"The Electrician"

PRIMERS.

BEING

A SERIES OF HELPFUL PRIMERS ON ELECTRICAL SUBJECTS,

FOR THE USE OF

STUDENTS AND GENERAL READERS.

VOL. I.—THEORY.

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PREFACE.

THE object of "The Electrician" Primers is to briefly describe in simple and correct language the present state of electrical knowledge. Each Primer is short and complete in itself, and is devoted to the elucidation of some special point or the description of some special application. Theoretical discussion is, as far as possible, avoided, the principal facts being stated and made clear by reference to the uses to which they have been put. Both volumes are suited to readers having little previous acquaintance with the subject. The matter is brought up to date, and the illustrations refer to instruments and machinery in actual use at the present time.

It is hoped that the Primers will be found of use in Schools, Colleges, and other Educational and Training Establishments, where the want of a somewhat popularly written work on electricity and its industrial applications, published at a popular price, has long been felt; while artisans will find the Primers of great service in enabling them to obtain clear notions of the essential principles underlying the apparatus of which they may be called upon to take charge.

June, 1891.

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By J. A. FLEMING, M.A., D.Sc. (Lond.)

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THE EFFECTS OF AN ELECTRIC CURRENT.

The presence of an electric current can only be recognised by the effects it produces, since its inner nature is quite unknown. A wire is said to convey an electric current when it is endowed with certain properties it does not usually possess. Some of these properties are exhibited within the wire itself, while others are exhibited at a distance from it. Thus the heating effect of an electric current occurs within the conductor through which it is supposed to flow, while the magnetic influence of the current is felt in the medium outside the wire. An electric current may in many respects be usefully compared with a current of water; but the analogy must not be pursued too far, since the electrical phenomena are much more complex and are not confined within the channel through which the flow takes places.

The effects which an electric current produces would be of very little practical value if it were not possible to control with certainty their magnitude and place of action. A current produces heat whenever it flows and whatever the conductor may be; but the total heat produced in passing through many yards of copper wire may be quite inappreciable compared with that produced by the passage of the same current through a short thin piece of platinum. It is this possibility of concentration which renders electricity so economical an agent for distribution at a distance. Thus, for electric lighting purposes, the conductors conveying the electricity from the central station are made thick and of good conducting metal, so that little waste occurs, while in the lamps themselves, where the heating or luminous effect is required, the conductor is made very thin and badly conducting. The electrical firing of mines and torpedoes is, for the same reason, designed so that the heating effect only occurs to any appreciable extent in the fuse where the heat is wanted, the conducting wires remaining quite cool. A very important

application of the heating effects of electric currents has recently been developed under the name of electric welding, and consists of passing a strong current across the junction of two pieces of metal until they become white hot, and afterwards completing the weld by hammering. Perhaps no process shows more than this how far it is possible to concentrate the heating produced by electrical means, for two metal bars may be taken, each a foot long and more than one inch thick, placed end to end, the junction fused by the passage of a current, and the weld completed before the other ends have become too hot (by conduction of the heat along the bar) to hold in the hands without discomfort. Nearly all the safety devices used in electric lighting owe their action to the heating effect of electric currents, and their economy to the possibility of concentrating it. The uses to which electrical heating has been put are very numerous, and are by no means exhausted. In America it has recently been proposed, and with fair probability of success, to increase the tractive power of locomotives by passing a strong current from the wheels to the rails. The heat produced may be made sufficient to produce a temporary fuse or weld, and so increase the friction, without at the same time adding to the load on the engine; and the economy effected by this process is said to be considerable. It is also probable that in future rooms and buildings will be warmed, to a great extent, by electric heaters, instead of by ordinary fires or steam pipes; for although the system at present is not so economical as the others, it is more cleanly and may yet prove a commercial success.

Closely allied with the heating effect of a current is the luminous effect. The intense heat generated by passing a current across a gap formed between two carbon points, technically known as the "arc," is sufficient to render the carbon incandescent and to give rise to a brilliant arc light; while by passing a current through a thin carbon filament completely enclosed within a glass vessel from which all the air has been exhausted, the light of the glow lamp is obtained. By means of an arc lamp we can produce a very bright light within a very small space, so that arc lights are peculiarly well adapted for focussing purposes, such as for lighthouse illumination and for head lights; while the glow lamp is unique in being the only light which can be continuously produced within a completely closed vessel, and is, therefore, especially suitable for the lighting of mines. No light can be

produced without heat, but a given amount of illumination can be produced with less heat by electrical means than in any other manner. An arc light only produces one-fifth part of the heat given out by the same amount of gas light, while the glow lamp produces a trifle more than one-third.

The strangest effect produced by a current on the conductor through which it flows is exhibited in certain classes of liquids called electrolytes. The only result of passing electric currents through metallic conductors is that their molecular structure is slowly changed; copper wires becoming quite brittle after long use. With certain liquids, however, the passage of the current produces continuous decomposition. In some cases, gases only are given off, while in others metal is deposited. The industries of electrotyping and electrometallurgy are based upon these results; while there are several minor applications, as for instance electrical bleaching, and the purification of sewage. The electrolytic effects of an electric current have been of great use in chemistry, and it was by means of them that several new elements were discovered; and the same process is now employed on a large scale in the extraction of aluminium from clay.

The magnetic effects of an electric current are, however, the most remarkable and important of all. A current flowing along a wire exerts a magnetic force on the poles of a magnetic needle, and if the latter is free to move it will turn and set itself so that it is at right angles to that wire and to the line joining the needle to the wire. If the direction of the current is reversed the needle will turn completely round. Magnetic force is remarkable, not only because it acts at a distance without any visible agency, but because of its curious direction. No other force is known which acts at right angles to the direction of the agent causing it. The magnetic force rapidly diminishes in intensity as the distance from the conductor conveying the current is increased, but with sufficiently delicate apparatus it may be detected at very great distances. It has, indeed, been possible with the telephone to distinguish variations of a current in a wire, not directly connected with the telephone, more than two miles off.

An electric current is capable of magnetizing iron, and, to a less extent, nickel, cobalt, and other metals. The strongest magnets are made by winding many convolutions of wire round a soft iron core and passing a current through the coil. The magnets so produced attract and repel each other in the same

way as ordinary permanent magnets; and electric motors, so much used for traction and other motive purposes, are in principle nothing more complex than machines by means of which fixed electro-magnets are made to exert a continuous rotating force upon an armature, *i.e.*, an iron ring made magnetic by the passage of the current.

The magnetic influences exerted by currents, the magnitude of which is changing more or less frequently, as is the case with alternating or intermittent currents, are of more practical importance than those caused by steady currents. Telegraphy and telephony involve changing currents. It is a property of changing currents to cause similar currents to flow in neighbouring conductors, although there may be no metallic connection between them; and one of the most important systems of electric light distribution (*see* Primer 34, Vol. II.) is based on this fact.

The following books may be recommended to those wishing to gain further information on this subject:—

"Practical Notes for Electrical Students." Vol. I. By A. E. Kennelly and H. D. Wilkinson.

"Elementary Lessons in Electricity and Magnetism." By S. P. Thompson.

"Electricity." By E. M. Caillard.

CONDUCTORS AND INSULATORS.

Any material which will allow an electric current to pass through it is said to conduct electricity, and is called a conductor. The current which will flow through any given conductor, in consequence of applying a difference of electric pressure or potential at the two ends, is dependent on the magnitude of a physical property of the conductor called its resistance.* The greater the resistance of a body, the smaller the current which a given electrical pressure will produce. The resistance of a conductor depends on its length and cross-section, and also on the nature of the material itself. Different substances vary enormously in this property of resistance. All bodies conduct electricity to some extent, but a sheet of copper would in less than a second transmit far more electricity across it than a similar layer of ebonite would be able to accomplish in a century under the same circumstances. In fact, the resistances of some bodies differ as much from each other as an inch differs from the distance of the stars. Materials are compared with reference to their resisting properties by calculating from experiment the resistance which a unit cube, formed of the substance, would present to the passage of electricity between two opposite faces. If this resistance is very small the substance is said to be a good conductor, whereas if it is very large it is called a bad conductor, or insulator. The terms are, however, merely comparative, and it is possible for a substance to be a conductor for one purpose and an insulator for another. Thus, if the bare ends of two wires leading to an

* The reciprocal of the resistance of a conductor is known as its *conductivity*, and some writers prefer this expression. A wire of high resistance is with them one of low conductivity, and *vice versâ*.

electric bell are touched by the hands, the ringing of the bell is not affected, because the body acts as an insulator and does not conduct away sufficient current to make any appreciable difference to that which flows through the coils of the electric bell. With a sensitive galvanometer, however, the current which flows through the body can easily be detected, and may far exceed those which can be sent through really good insulators.

All the best conductors are metals; and the purer the metal the better it conducts. The chief metallic conductors, in order of conducting power, are silver, copper, gold, zinc, platinum, iron, tin, lead, and mercury. Copper is nearly as good a conductor as silver; iron has about six times the resistance of copper, while lead has about twelve times, and mercury sixty times, as much resistance. Liquids have far more resistance than solids; and gases far more than liquids. When electrical currents have to be used, as in commercial practice, for producing light or conveying power to a distance, it is highly important to have the wires or leads as good conductors as possible, because the heating effect and waste of power is proportional to the resistance; and when the currents used are large the waste becomes a great consideration. The substance universally used for the electric conductors or leads is copper, because it is practically as good a conductor as silver, while it is much cheaper. The next best commercial substance is iron; but this, although much cheaper than copper, has six times the resistance, and wires made of this material would, in order to present no more resistance than the corresponding copper wires, have to be made six times as heavy. Such wires would be much more troublesome to manage, and would after all be more costly. In many cases large amounts of power have not to be transmitted, and small currents are sufficient, as in the case of telegraphy. The waste in the wires is then unimportant, and iron wires may with advantage be used owing to their comparative cheapness; but copper wires are necessary for electric lighting purposes, and it is important that the copper should be of the highest conductivity, *i.e.*, of the lowest resistance. The presence of a small amount of impurity produces a striking diminution of the conductivity of a metal. Thus one-half per cent. of carbon reduces the conductivity of copper nearly 30 per cent., while two per cent. of phosphorus diminishes it to one-tenth of its original value. A trace of arsenic reduces it by 40 per cent., one per cent. of zinc causes a diminution of 20 per cent., and one-half per cent. of

iron reduces it more than 60 per cent. One consequence of the importance to electricians of high-conductivity copper, is that it can now be obtained in the market very pure indeed, although some years ago market copper used to contain traces of several foreign substances.

Alloys of two different metals generally conduct worse than either; thus, an alloy of one per cent. of silver with 99 per cent. of copper conducts only 90 per cent. as well as copper, although silver is the better conductor of the two. Several alloys have been used for resistance coils and other electrical apparatus in which the quality of resistance is itself a desirable thing. Among such may be mentioned German silver, platinum silver, and platinoid.

Insulators are as much needed for electrical purposes as conductors, for it is only by means of the former that the current can be confined to flow in the direction intended. Cotton, silk, bituminous substances, india-rubber, gutta-percha, and air are all insulators; cotton being the worst, and dry air the best. Of these, cotton, silk, and india-rubber are much used for covering thin wires; while most of them are employed for covering the thicker wires or leads used in electric lighting. Insulating substances are chiefly needed to prevent electrical contact with the earth; for the ground, although very inferior in conducting power to copper, may yet be able to carry off a quite appreciable fraction of the current, owing to the extent of the surface exposed. The difficulty about insulators does not arise in the manufacture of an article which will stand all requirements when new, but lies in the uncertain durability of them when subjected to varying climatic changes and to the rough treatment necessarily occurring in practice. The best and most reliable insulator for most practical purposes is pure india-rubber, because of its durable and flexible nature, its power of withstanding moisture, and its freedom from the action of acids. Gutta-percha is without any serious rival when wires have to be put under water, and submarine telegraphy would hardly even now be possible without it, so much does it, when its cost is considered, excel other substances in its power of withstanding high pressures and in its impermeability to salt water. The demand for gutta-percha now exceeds the supply, and the price of this material is far greater than it was, and its quality much inferior. A good substitute is much needed.

Gutta-percha is, however, quite unsuited for permanent insulation when exposed to the atmosphere, as after a time it becomes brittle and useless for such purposes. India-rubber cannot be extensively used in the pure state on account of its great cost, but it is very largely employed compounded with sulphur and other insulating substances, as in ebonite, vulcanite, okonite, &c.

The amount of insulation required depends upon circumstances. When very large currents are used the potential, or electric pressure, employed is generally small, and the insulation need not be very good. With high potential systems much greater precautions are necessary in regard to the insulation, in order to ensure freedom from accidents, and the manufacture of cables for such purposes is very elaborate.

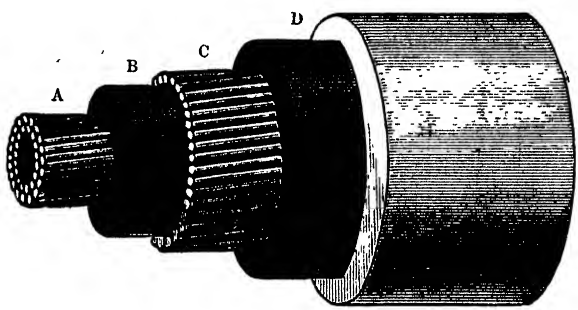


Fig. 1.

For instance, the Ferranti cables for use at the Deptford installation consist of two concentric copper tubes, insulated from each other by layers of brown paper soaked in a bituminous compound. In order to give the cable great mechanical strength the whole is afterwards enclosed in an iron tube. For lower potential systems the cables may be laid in bitumen, or may consist of bare conductors supported on porcelain insulators in watertight conduits.

A specimen of an "armoured" electric light cable is illustrated in Fig. 1, A and C being copper wire conductors, B and D the insulating material, and E the lead covering to exclude moisture. Such a cable as this might be further protected by an armour of steel wire, which would be put on over the lead, with a serving of

cotton or jute between. As an additional protection from the action of salt water, &c., a waterproof braiding is usually added over all.

Telegraph lines are insulated from the ground by means of porcelain insulators, so constructed as to have a large surface exposed between the wire and the support for the insulator. In Fig. 2, which represents Latimer Clark's double cup form of insulator, it will be seen that there is a large surface between the wire at *a* and the iron stalk *s*, and that before any leakage can take place down the post it is necessary for the current to pass over the two outer and the two inner surfaces. The leakage

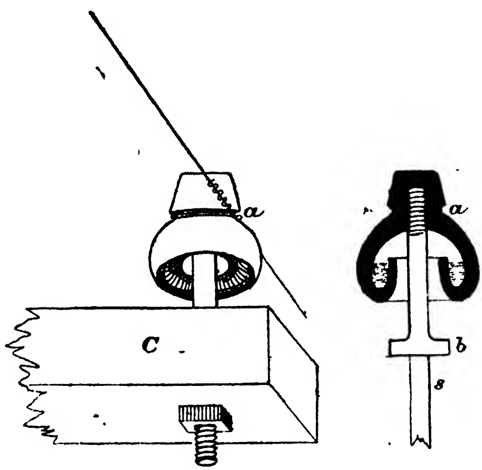


FIG. 2.

which takes place at such insulators is entirely due to the state of the surface, for the porcelain itself conducts practically nothing. The state of the atmosphere consequently makes a great difference in the leakage which occurs. Actual tests have shown that the resistance of a particular insulator was 60,000 megohms at noon on a warm day, while early next morning, after a heavy dew, the resistance had fallen below 200 megohms, and the next day the resistance, taken in the pouring rain, was 1,000 megohms. The leakage occurring with good insulators is almost wholly superficial, and hence in laboratories where high insulation is needed the ebonite supports of galvanometers are

often corrugated in order to present a larger surface, and a thin film of paraffin wax is often laid over the insulating surfaces, because such a film remains clean and dry when exposed to the atmosphere longer than any other covering which can be applied.

The following books may be recommended to those wishing to gain further information on this subject:—

"Elementary Lessons in Electricity and Magnetism." By S. P. Thompson.

"Practical Notes for Electrical Students." Vol. I. By A. E. Kennelly and H. D. Wilkinson.

"Practical Electricity." By W. E. Ayrton.

"The Electrician" Primers.—**No. 3.**

OHM'S LAW.

No exact ideas are possible about the action of electricity without a thorough understanding of Ohm's Law. This is as necessary to the electrician as correct ideas about the strength of materials are to the engineer. An electrical engineer has to deal quantitatively not only with electrical currents, but also with the pressure or potential at which they are supplied. The power of a river to turn a waterwheel is dependent both on the magnitude of the current of water and on the amount of the fall which the water suffers. The most important thing an engineer has to deal with is power, or rate of doing work; and this is measured both with electricity and with water by the product of the current and the difference of pressure or head. Instruments can be made to measure both quantities; but an engineer must not rely on subsequent measurements, he must be able to calculate in advance, and it is in this connection that Ohm's Law is so important, for it states the relation between current and potential, and its value is all the greater because the relation is a simple one.

No relation such as Ohm's Law can be established until a general agreement is arrived at as to the way in which currents and potentials are to be measured. We have seen in Primer No. 1 that an electric current produces effects of various kinds, and each one of these may be taken as a basis of measurement. They are, however, not all equally suitable. Thus the strength of a current might be regarded as proportional to the excess of temperature of the conductor heated by the current above that of the atmosphere; but this would be a very bad definition, for the excess in question would be dependent on many circumstances over which the current would have no influence; it would be a very inconvenient definition of current strength, it would not fit in with any other, and it would be impossible to make measuring instruments agree among themselves. There are, however, two effects of an electric current which are found to be strictly proportional to each other. The magnetic force exerted by a current is found to be accurately proportional to the rate of decomposition of an electrolyte placed in circuit. If several voltameters or electro-

lytic resistances are placed one after the other in the same circuit, the rates of decomposition bear a constant ratio to each other; so that if one is doubled all the others are doubled, even though the electrolytes are quite different in the various voltameters. The magnetic and electrolytic definitions of current strength thus lead to the same result; and, chiefly for this reason, the magnetic definition is adopted, and current meters are graduated in accordance with it. Similar reasons determine the way in which potential is measured, the definition adopted depending on the force of attraction exerted between two electrically charged parallel plates whose linear dimensions are large compared with their distance apart.

Ohm's Law states that the difference of electric pressure, or potential, required to drive a current through a given conductor is strictly proportional to the magnitude of the current while the physical state of the conductor remains the same. The ratio of the two is defined to be the resistance of the conductor. This definition of resistance implies that the current (measured in amperes) flowing through a conductor is obtained by dividing the electric pressure or difference of potential (in volts) at its terminals by the resistance of the conductor measured in ohms. The Law of Ohm implies more than this, however, for it states that a conductor whose resistance is one ohm has always a resistance of one ohm whatever the current flowing through it may be, provided only that no external influence, or indirect action of the current itself, conspires to alter the physical state of the conductor. The resistance of a conductor is thus a physical property of the substance itself, and is not dependent on the current flowing through it. If the resistance of a material varied with the current flowing, it would be very much harder to make calculations about conductors than it is by using Ohm's Law. To take an illustration from mechanics, if we are told that a given material will stand a pull of 2 tons per square inch we know that a bar whose section is 4 square inches will stand a pull of 8 tons, because we are aware that, so long as the physical state of the material is not altered by heating or any other means, the strength of a bar is proportional to its section. This law, which corresponds with Ohm's Law, is very convenient for calculation, because, by means of one constant for a given material, we can calculate the strength of a bar of that substance, no matter what its section may be, by simply multiplying the section by the constant. In the above instance the constant 2 tons per square inch

would be of little use to us if we were told it only applied to bars whose section was 4 square inches, and that for bars of any other section the constant would be different. Ohm's Law enables us to calculate from the dimensions of the conductor and a single constant of the material, called the specific resistance, what the resistance of the conductor is. We have no need to take the current into account, because it makes no difference.

The resistance of a conductor is proportional to its length; for if we take two similar conductors of resistance one ohm and join them in series, so that the end of one is connected with the beginning of the other, each will require one volt difference of potential to send an ampere through it, and hence the difference of potential at the unjoined ends when the current flowing is one ampere will be two volts. The resistance of the combined conductors, being by definition the ratio of the volts to the amperes, will therefore be two ohms, or twice the resistance of each. We may see similarly that the resistance of a conductor is inversely proportional to its section; for, if we connect the above-mentioned conductors in parallel, so that they are joined together at each end, and send a current through the combination, a difference of potential of one volt maintained at the ends will drive a current of one ampere through each conductor, and the total current transmitted by the compound conductor will be two amperes. The resistance will thus by definition be half an ohm, or half the resistance of the single conductor, while the section is double. To obtain the resistance of a conductor we thus multiply the specific resistance of the material by the length of the conductor and divide by the section. The resistance of a copper wire 1 mile long and one quarter of an inch in diameter may thus be calculated as follows:—

The specific resistance of copper is 1·6 microhm (millionths of an ohm) per cubic centimetre.

The length of the conductor is 1760×36 inches,

or $$1760 \times 36 \times 2{\cdot}54 = 161{,}000 \text{ centimetres.}$$

The section of the conductor is $\frac{\pi}{4}(\frac{1}{4})^2$ square inches,

or $$\frac{\pi}{4} \times \frac{2{\cdot}54}{4} \times \frac{2{\cdot}54}{4} = {\cdot}32 \text{ square centimetre,}$$

and the resistance of the conductor is thus,

$$\frac{161{,}000}{0{\cdot}32} \times \frac{1{\cdot}6}{1{,}000{,}000} \text{ ohms} = 0{\cdot}8 \text{ ohm.}$$

As the specific resistance of copper is 0·6 microhm per cubic inch, we might have calculated the resistance of the above con-

ductor without introducing the factors 2·54 if we had used the constant 0·6 instead of 1·6; but whether the centimetre or the inch be used for the unit of length it is always necessary to reduce the dimensions to the particular unit chosen.

Having calculated the resistance R of the conductor in ohms, we can find the number of volts V required to send a current C amperes through it by means of the formula,

$$V = CR;$$

and if a battery of electromotive force E and internal resistance r have its terminals connected with the ends of the conductor in question, the current flowing, which is obtained by dividing the electromotive force of the circuit by the *total* resistance, will be given by the formula,

$$C = \frac{E}{r + R}.$$

The volts needed to drive this current through the battery will, in accordance with what we have said, be

$$v = C\,r.$$

The volts at the terminals of the wire—that is, the difference of potential at the terminals of the battery—is $V = C\,R$, so that by addition we have

$$V + v = C\,R + C\,r = C\,(R + r),$$

or, by comparison with the equation giving the value of C,

$$V + v = E.$$

So that the electromotive force E of the battery, which is a constant, is spent, partly in driving a current through the battery itself, and partly in sending the current through the wire; and the potential difference at the terminals of a cell differs from its fixed electromotive force by the number of volts necessary to drive the current through the battery. Although the electromotive force of a battery is constant, the useful part of it, that available for external purposes, varies with the current sent, unless the internal resistance of the cell is inappreciable.

The value of V is not always less than E.

When a current is sent through the battery in the opposite direction to that which the cell would naturally produce, V exceeds E by the product of $C\,r$.

The following books may be recommended to those wishing to gain further information on this subject: –

"Practical Notes for Electrical Students." Vol. I. By A. E. Kennelly and H. D. Wilkinson."

"Elementary Lessons in Electricity and Magnetism." By S. P. Thompson.

PRIMARY BATTERIES.

Most bodies have stored up in them a certain amount of energy, or power of doing work; and if we treat them in a suitable manner we can, in general, make them give up some of this energy—that is to say, we can make them do work. The process usually consists in causing them to combine with some other body, whereby a new substance is formed, having a smaller store of energy

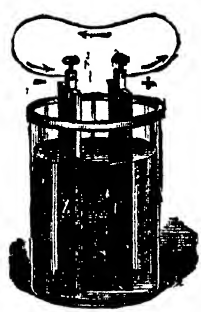


Fig. 1.

than had the original material. We can also reverse this process, and, by putting energy into compound bodies, produce other substances which have the power to do work. Thus by the application of heat to zinc ore, we can separate the zinc from the oxygen and other things with which it was combined, and we shall have stored up in the zinc some of the energy liberated by burning coal during the operation of smelting, for zinc is a body having a greater store of energy than zinc ore. Having stored up energy in the zinc, we can get it out again by reconverting it into some zinc compound having a less store of energy; and the most convenient method of doing this is to use the zinc in a primary

battery,* whereby we obtain some of the stored energy as an electric current.

The simplest arrangement for effecting this purpose is shown in Fig. 1, which represents a primary or voltaic cell or element. A plate of zinc (Z) and a plate of copper (C) are immersed in dilute sulphuric acid (one part of acid to ten parts of water) contained in a glass vessel. If these materials are pure, no chemical action will take place until the plates are electrically connected together by means of a wire, as shown in the figure : then, however, the zinc is attacked by the acid and an electric current set up. (It may be here noted that in all primary batteries it is necessary that the plates should not touch each other inside the liquid.) The chemical reaction which takes place is quite simple: sulphuric acid is a compound of sulphur, oxygen, and hydrogen, the two former of which combine with the zinc to form zinc sulphate (a compound having less energy than zinc), and the hydrogen is given off as bubbles of gas at the surface of the copper plate. If the plates are kept electrically connected together, the current will continue till either the zinc or the acid is used up.

It is not, however, necessary to use plates of zinc and copper; almost any pair of dissimilar solid bodies which are conductors of electricity, immersed in almost any liquid, will form a voltaic cell, but the effect will, in most cases, be very small. Nor is the simple arrangement shown in Fig. 1 a particularly good one, as it is found that the hydrogen which is liberated at the copper plate does not all escape, some of it adhering as a sort of film, which, being a non-conductor of electricity, offers a resistance to the current. Owing to this action, which is known as *polarisation*, the current rapidly diminishes when the cell has been in use a short time.

The most obvious way of getting rid of this polarisation is to surround the copper plate with something which will combine with the hydrogen, and the attempts of various inventors to discover the best material for this purpose have resulted in many different arrangements. Historically the first of these was that devised by Daniell, who used a solution of sulphate of copper as the depolarising fluid. Copper sulphate is a compound of sulphur, oxygen, and copper; and the hydrogen set free at the copper plate combines with the sulphur and oxygen, forming sulphuric acid, while the copper is deposited as a metallic film on the copper

* Strictly speaking, a *battery* is composed of several *cells*, but a single cell is, however, frequently spoken of as a battery.

plate. It would not do, however, to merely immerse a pair of zinc and copper plates in a mixture of dilute acid and copper sulphate, as the latter would in this case at once act on the zinc, forming metallic copper and zinc sulphate: the copper sulphate and the zinc have to be kept quite separate from each other, while at the same time they must be electrically connected together. This object is attained by using a vessel of unglazed earthenware (known as a *porous pot*), in which is placed the zinc and dilute acid, and immersing the whole in a larger vessel containing the copper and copper sulphate solution. Batteries of this construction have been largely used for telegraphy, for which purpose they are well suited, as from them we can obtain a weak but steady current for a prolonged period. It is usual to add sulphuric acid to the copper sulphate solution to improve its conducting power,

Fig. 2.

while the zinc is commonly immersed in a solution of zinc sulphate instead of dilute acid. This zinc sulphate does not act upon the zinc; but some of the acid which, as explained above, is produced by the action of the hydrogen on the copper sulphate, soaks through the porous pot. In what is known as the gravity Daniell cell the porous pot is omitted; the strong solution of copper sulphate being heavier than the zinc sulphate, the latter can be made to float on the top of the former, and if the cell is carefully set up there will be practically no admixture of the two fluids.

Another liquid having a great affinity for hydrogen, and one which may be advantageously employed as a depolariser, is nitric acid, which is used in the batteries of Grove and Bunsen. If we arrange a plate of zinc in dilute sulphuric acid and a platinum plate in a porous pot full of strong nitric acid, we have Grove's

battery; if we substitute carbon for the platinum, as shown in Fig. 2, we have Bunsen's modification of it, the action being the same in each case. It is necessary to use platinum or carbon, as copper or almost any other metal would be dissolved by the nitric acid; and carbon has an important advantage over platinum, inasmuch as it is less costly. The form of carbon used is either a very dense kind of coke found in gas retorts, and known as gas carbon, or a similar material artificially manufactured.

Nitric acid batteries will give a strong and steady current, but are rather costly and produce exceedingly unpleasant fumes: chromic acid is therefore frequently substituted for nitric acid. We can use a cell with a porous pot as shown in Fig. 2, but as

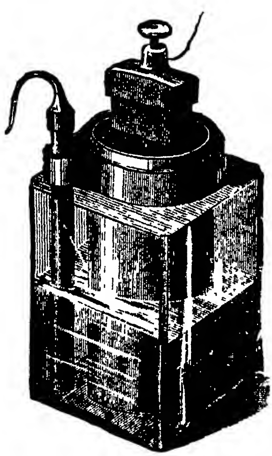


FIG. 3.

chromic acid will of itself act on the zinc in the necessary manner, we may omit the porous pot and simply immerse the plates of zinc and carbon in the acid solution. This solution may be prepared by dissolving oxide of chromium in water, producing chromic acid, or by adding strong sulphuric acid to a solution of potassium bichromate, which gives us chromic acid and potassium sulphate. The proportions in the latter case may be: Water, 1 pint; bichromate of potash, 3oz.; sulphuric acid, 9oz. The bichromate should be powdered and dissolved in the water, and the acid slowly poured in, with constant stirring.

The Leclanché is a form of cell which is very useful for electric bells and other purposes for which a comparatively weak

current is required at intervals. It is usually made as shown in Fig. 3. The porous pot contains a carbon plate packed round with a mixture of small pieces of coke and dioxide of manganese: this, together with a zinc rod, is placed in a glass vessel partly filled with a solution of sal ammoniac.

If the zinc used in a primary cell is quite pure, no action will take place until the circuit is completed by connecting the plates together, and a current is established; but ordinary commercial zinc is attacked by dilute sulphuric acid even when no current is flowing. This would result in a considerable waste of zinc, but it is found that zinc amalgamated with mercury acts as if it were pure. Battery plates are therefore always amalgamated, which is effected by first cleaning them with dilute sulphuric acid, and then pouring on them a few drops of mercury, which should be rubbed in till the whole surface is uniformly bright.

It is usual to speak of an electric current as if there were an actual flow of some sort of fluid along the wires conveying it, and to say that the current flows in a particular direction, not because we wish to convey the idea that any such flow actually occurs, or that an electric current in a wire resembles a stream of water in a pipe, but because it is convenient to make use of this conventional form of expression in describing electrical phenomena. The direction of the current is expressed by saying that one part of an electric circuit is positive (+) and another negative (−), when the current is flowing from the positive towards the negative. In the wire joining the plates of a voltaic cell, the current flows from the copper or carbon towards the zinc (Fig. 1) so that the copper is the positive *pole*, while the zinc is the negative.

In order to compare various sorts of primary cells it is necessary to know their *electric pressure* or *electromotive force*, which is measured in *volts*, and their electrical *resistance*, which is measured in *ohms*. The electric pressure depends only on the metals and liquids employed, and in the different cells above described is as follows: Zinc and copper plates in dilute sulphuric acid, 1·05 volt; Daniell cell, 1·1; Grove or Bunsen, 1·9; bichromate, 1·7; Leclanché, 1·4. The resistance depends on the fluids used, on the size of the plates and their distance apart, and is, other things being equal, inversely proportional to the area of plate in the liquid, and directly proportional to the distance between the plates. It is sometimes convenient to use several small plates of each kind connected together instead of one large one: in this case

the resistance is inversely proportional to the sum of the areas of the separate plates. It is not possible to specify the resistance of different forms of cells exactly; but that of a Daniell is usually about 0·5 ohm, that of a Grove cell of the most common size about 0·15 ohm.

Many attempts have been made to introduce primary batteries for electric lighting, but hitherto they have been found too costly and troublesome to be of much practical service. In most cases some modified form of chromic acid cell has been used, and the following figures may be taken as roughly indicating the size of battery required. If we arrange 12 cells having an effective area of plate of 200 square inches, in containing vessels each of about 1,000 cubic inches capacity, we shall be able to illuminate 6 incandescent lamps of 8 candle-power for about 12 hours.

The following books may be recommended to those wishing to gain further information on this subject:—

"Practical Notes for Electrical Students." Vol. I. By A. E. Kennelly and H. D. Wilkinson.

"Elementary Lessons in Electricity and Magnetism." By S. P. Thompson.

"Practical Electricity." By W. E. Ayrton.

THE ARRANGEMENT OF BATTERIES.

In order to produce any pre-arranged effect by means of batteries (either primary or secondary), it is necessary to know how many cells we must use, how large they must be, and in what manner we must connect one cell with another, in order to have the best conditions for the production of that effect. In order to ascertain this, we have to consider how we describe the magnitude of the various electrical quantities involved.

If we wish to establish an electric current in a continuous circuit of electrically-conducting material, we have to set up a difference of electric potential, or electric pressure, between the different parts of that circuit: the tendency being always for an electric current to flow from a point of high potential to a point of lower potential. This difference of pressure may be caused by a battery, dynamo, or other electric generator, and the difference of pressure existing between any two points may be measured by a *voltmeter* in terms of a unit known as a *volt*. The effect produced in the circuit does not, however, depend on the pressure which causes the current, but on the strength of the current, which is defined as the quantity of electricity which flows past any point in a unit of time: this quantity may be measured in *amperes* by an *ammeter*. Now, we know from experiment what strength of current is needed to produce any given effect; and in order to design an electric circuit to produce that effect we have to determine the difference of pressure which will cause that current to flow. That is to say, we have to ascertain the *resistance* which our circuit is going to offer to the flow of the current; and this quantity can be measured by various methods in units of resistance, or *ohms*. The relationship existing between strength of current, electric pressure, and resistance, is expressed by a law known, after its discoverer, Ohm, as Ohm's Law (*see* Primer No. 3), which states

that the current strength is proportional to the electric pressure, and inversely proportional to the resistance; or, using the letters C for current strength, E for difference of pressure, and R for resistance, we can say that C is proportional to $\frac{E}{R}$. If we choose our units properly, we can write this, $C = \frac{E}{R}$; and the practical units used by electricians have been so selected that the number of volts which measures the pressure, divided by the number of ohms which expresses the resistance, gives the strength of current in amperes.

As is pointed out in Primer No. 4, on "Voltaic Batteries," different forms of cell produce various differences of pressure, generally something between 1 and 2 volts, and have resistances which depend chiefly on their dimensions, and which may be anything from a few ohms to a small fraction of an ohm. If we require a greater difference of pressure than about 2 volts, we can

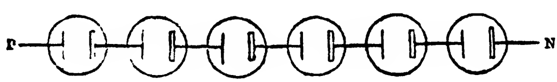


Fig. 1.

obtain it by using a number of cells, and connecting them up *in series*—that is to say, joining the positive terminal of the first cell to the negative terminal of the second, and so on throughout, the rest of our circuit being joined to the negative terminal of the first cell and the positive of the last, as shown in Fig. 1. By this arrangement we add together the pressures of the individual cells, and if we have n cells of 2 volts each, the whole pressure will be $2 \times n$ volts. We have also added the resistances of the separate cells; so that if the resistance of each cell is r ohms, the resistance of the whole battery will be $n \times r$ ohms.

Let us now suppose that we wish to work, by means of primary or secondary batteries, an electric lamp which we know, from previous experiments, requires a current of 1 ampere to raise it to its proper brightness, and has a resistance of 50 ohms. Let us also suppose that we have at our disposal a number of small cells each giving a difference of pressure of 2 volts, and having a resistance of 1 ohm: we wish to find out how many of these cells we shall require if we connect them up in series. If we call this number of cells n, the total electric pressure will be $2\,n$ volts,

and the total resistance will be, 50 ohms in the lamp, and n ohms in the battery (we assume, for simplicity, that the connecting wires have no resistance); and we wish the current strength to be 1 ampere. If, now, in the equation $C = \frac{E}{R}$, we insert these values of the current, pressure and resistance, we shall have

$$1 = \frac{2n}{50 + n},$$

and the solution of this equation gives $n = 50$. We shall, therefore, have to use 50 cells, and the total pressure will be 100 volts, while the resistance of the battery is 50 ohms.

In the above example we are sending a current of 1 ampere through a resistance of 50 ohms, so that the pressure at the terminals of the lamp will only be 50 volts: yet the pressure in the whole circuit is 100 volts. This is owing to the fact that we are sending a current of 1 ampere through a battery having a resistance of 50 ohms, and it requires a pressure of 50 volts to do this. Now, in any electric circuit the *work* done is measured by the product of the current and the pressure: 1 ampere multiplied by 1 volt being equal to 1 *watt*. (The *watt* is the electrical unit of rate of doing work, and is the $\frac{1}{746}$th part of 1 horsepower.) In our lamp we were using a current of 1 ampere at a pressure of 50 volts, so that we were expending 50 watts, for which we get a light of about 15 candle-power; but we were also expending 50 watts in the battery, for which we get no return. It is, therefore, clear that we were wasting half our power in sending the current through the battery; so that the arrangement is far from being an efficient one. The remedy is obviously to diminish the resistance of the battery, and this we can do by increasing the size of the cells. Let us then suppose that instead of using small cells, having each a resistance of 1 ohm, we use much larger ones, having only $\frac{1}{13}$th of an ohm resistance. Then as before, the number of cells can be found from the equation

$$1 = \frac{2n}{50 + \frac{n}{13}}$$

whence we see that we shall only require 26 such cells, and that the total pressure is 52 volts and the resistance of the battery $\frac{26}{13} = 2$ ohms. The useful work done is in this case 50 watts, as before, but only 2 watts are wasted in the battery.

We can, however, attain the same end by the use of a number of small cells. If, instead of connecting our cells in *series*, we connect them in *parallel*—that is, if instead of connecting the positive plate of one cell to the negative plate of the next, as shown in Fig. 1—we join all the positive plates together and also all the negative plates together, as shown in Fig. 2, we shall have an arrangement which acts like one large cell.

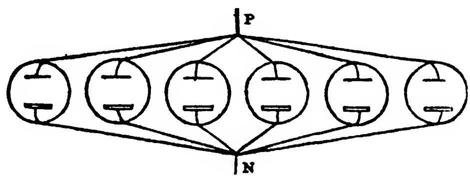
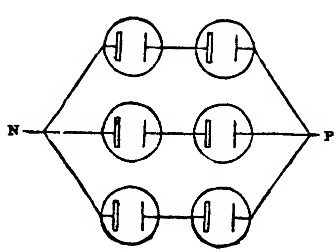


Fig. 2.

If each cell has a pressure of 2 volts, then n cells connected in parallel will have a pressure of 2 volts; but as there are now n paths for the current, the resistance of the group will only be $\frac{1}{n}$th the resistance of a single cell. If we arrange several such groups of cells connected in parallel (or as it is sometimes termed, *multiple arc*), we can then connect the groups in series, as shown in Fig. 3; the pressure of such an arrangement



being equal to the pressure of one cell multiplied by the number of groups in series, and the resistance being equal to the resistance of one cell divided by the number of cells in each group and multiplied by the number of groups. If we wished to economically use small cells of 1 ohm resistance for working the above-mentioned lamp, we might connect them in groups of 13 in parallel, giving a resistance of $\frac{1}{13}$ ohm per group, and use 26

groups in series. We could not, of course, in any case use less than 26 cells in series; if we used 25, the total pressure would be 50 volts, which is just enough to send the required current through the lamp, so that nothing is left over to overcome the resistance of the battery; 25 cells, in fact, could only be used if they themselves had absolutely no resistance.

We can deduce from the foregoing the general principles which should guide us in connecting up any given number of cells so as to get the greatest current through a given circuit. If the resistance of one cell is large, say 10 ohms, compared with that of the rest of the circuit, say ·1 ohm, the total resistance will be nearly proportional to the number of cells in series; it is, therefore, of no great advantage to connect a large number of cells in this way, as by doubling the number of cells, though we double the total pressure, we also nearly double the total resistance, so that the strength of current is not much affected. If, in this case, we connect a number of cells in parallel, however, the resistance of the whole circuit will be nearly inversely proportional to that number; or, as conductivity is the reciprocal of resistance, we may say that the conductivity of the whole circuit will be nearly proportional to the number of cells; and as the pressure is constant, the current will be nearly proportional to that number. If, on the other hand, the resistance of the cells is small, say ·1 ohm, compared with that of the rest of the circuit, say 10 ohms, the total resistance is not much affected by the method of connecting up the cells; so that the resistance being nearly constant, that arrangement which gives the greatest pressure will also give the greatest current—that is, it will be best to connect all the cells in series. In other cases it will be found that some series parallel arrangement will give the maximum current; in fact, we shall find that we get the strongest current when the cells are so connected up that the resistance of the battery is as nearly as may be equal to the resistance of the rest of the circuit.

The total electric pressure in a circuit is often spoken of as the electromotive force, or E.M.F. This should not be confused with the difference of electric pressure, or potential difference, existing between the points in a circuit, as the two quantities are by no means always identical. The electromotive force in a circuit is the *whole* tendency which exists for a current to flow in that circuit; the potential difference between any two points is the tendency which there is for a current to flow from one of

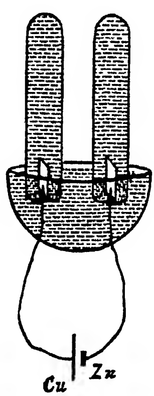
those points to the other. Now, it is the potential difference between two points which determines the strength of the current flowing in a wire joining them, and not the electromotive force of the whole circuit. If we have a battery whose terminals are not connected together, and which is therefore producing no current, the difference of potential between its terminals will be the same as its E.M.F.; but if we cause it to send a current, some part of its E.M.F. will be used to send that current through the cell, and the potential difference will be less than the E.M.F. by this amount. In the case of the 50 small cells described above, as working a lamp, the E.M.F. was 100 volts, but the potential difference between the terminals of the battery was only 50 volts.

ELECTROLYSIS.

Electrolysis is the breaking up of compound bodies by the use of the electric current.

Phenomena and Terms.

Suppose we take a vessel and fill it partly with acidulated water and place in it two plates of platinum having wires attached



to them, and having inverted tubes placed over them which contain acidulated water like the vessel; suppose we join to the two wires the poles of a battery of two or more Daniell's cells, we shall see that gases are given off at the two plates, and on testing the same it will be found that the gas given off at the plate connected with the zinc pole is hydrogen, and is double the volume of that given off at the other pole, which is oxygen. The terms which are employed in connection with this phenomenon are the following. The whole apparatus (excluding the battery, &c.) is called a *voltameter*; the liquid which is decomposed is called

the *electrolyte*; the two plates are the *electrodes*, that at which oxygen is given off being the *anode*, the other the *kathode*; the substances given off are known as *ions*, that given off at the anode being the *anion*, that at the kathode the *kathion*. Using these terms we may describe the above phenomenon by saying that, with platinum electrodes, on electrolysing acidulated water hydrogen is given off at the kathode and oxygen at the anode.

Suppose a similar experiment is tried with a solution of copper sulphate, using copper electrodes. On passing a current we shall find no gas is given off during its passage, but the kathode becomes gradually covered with new bright copper, while the anode is gradually corroded away; and if we were to weigh the electrodes before and after passing the current we would find that the increase of the kathode was about equal to the decrease of the anode.

A distinct difference will be found between these two typical cases: in one, different ions are liberated; in the other, there is apparently a transference of one ion from one side to the other. This effect is due to what is called a secondary reaction; and as these are very often of considerable importance, it will be well to devote a few lines to a short explanation. On the passage of the current the first thing that occurs is the breaking up of the copper sulphate into metallic copper, and a very unstable body, having no separate existence, known as sulphion. The latter immediately eats into the copper plate, at which it is given off, and forms new copper sulphate. Putting this down in chemical equations we have:—

$$(1)\quad 2\,CuSO_4 = Cu_2 + 2SO_4.$$
$$(2)\quad 2\,SO_4 + Cu_2 = 2CuSO_4.$$

If platinum or other incorrodible electrodes are used it is found that the liquid gradually becomes acid, copper being deposited on the cathode, and oxygen on the anode. In this case the sulphion breaks up the water round the anode; the actions are:—

$$(1)\quad 2\,CuSO_4 = Cu_2 + 2SO_4.$$
$$(2)\quad 2\,SO_4 + 2H_2O = 2H_2SO_4 + O_2.$$

Another very important difference between these two typical cases is the fact that a very much smaller electrical pressure is required in the second case than in the first. If we try to electrolyse the water in the first case with a single cell we shall find it impossible to do so, while the deposition of copper will take place

easily with one cell. The difference lies in that in the first case we have to overcome the chemical attractions between the atoms of hydrogen and oxygen forming the water, while in the second we simply substitute one atom of copper for another. The minimum electromotive force necessary to decompose any electrolyte is called the E.M.F. of polarization, and depends on the affinities of its constituents. For water it is about 1·5 volt.

Laws of Electrolysis.

By a full study of these and cognate cases of electrolysis, it has been found that the phenomena follow certain laws, of which the two chief are:—

1. The quantity of any ion liberated is proportional to the quantity of electricity which has passed.

2. One coulomb of electricity liberates a particular quantity of each ion, the quantity being called its electro-chemical equivalent.

From these two laws an equation can be framed which will give us the weight of a particular body deposited by any current in any time. If W is the weight in grammes deposited, A the current in amperes, t the time in seconds, and Z the "electro-chemical equivalent" of the body in question, the quantity of electricity which has passed is $A\,t$, and therefore $W = Z\,A\,t$.

For copper, $Z = \cdot000328$ gramme.
,, silver, $Z = \cdot001118$,,

Theory.

The theory by which an explanation of the facts observed can be given is due chiefly to Grotthüss and Clausius.

All the elements can be arranged in a series, beginning with those which are highly electro-positive and ending with those which are highly electro-negative in their character. Now, every body consists of molecules which are built up of atoms of these elements, and in the liquid these are all in a state of motion, the molecules themselves sometimes breaking up into atoms, which roam about free till they meet with other uncombined atoms and form new molecules. In the ordinary state of the liquid this breaking up and reconstitution takes place with no definite direction of motion of the free atoms being preferred to any other; but when a difference of electric pressure is set up between any two points of the liquid, the positive atoms, during the times they

are free, tend in one way, and the negative ones in the other; the result is that there is a liberation of ions at the two electrodes, which continues as long as the requisite electrical pressure is maintained.

Applications.

The practical applications of electrolysis are of immense and far-reaching importance, and increase yearly in number. Two of them, namely, the manufacture of secondary batteries and the various branches of electro-metallurgy, are separately considered in Primers Nos. 7 and 37. Two minor employments of electrolysis, namely, bleaching and sewage purification, may however be mentioned here.

Electric bleaching is performed by placing the substance which is to be bleached in a vat containing a weak solution of magnesium chloride. On passing a current through this chlorine is produced, which acts on the water and produces a substance of high bleaching power. When this has acted on the substance to be bleached, the chlorine recombines with the magnesium. There is thus no consumption of chemicals, but only of water and electrical energy.

Sewage has recently been very successfully treated by electrolysis with iron electrodes. All the offensive constituents are thrown down as a mud, which is sold for manure, the effluent being pure and clean.

In addition to such commercial uses, electrolysis is of great importance in physical laboratories: and by its means we are enabled to test the accuracy of instruments and calibrate them, and as a matter of fact the most correct way of testing the accuracy of an instrument is to compare its indications with those of a silver or copper voltameter.

The following book may be recommended to those wishing to gain further information on this subject:—

"Elementary Lessons in Electricity and Magnetism." By S. P. Thompson.

SECONDARY BATTERIES.

A SECONDARY BATTERY (sometimes called a storage battery, sometimes an accumulator) is an electrical arrangement by means of which energy can be chemically stored, or kept in stock as it were, for future use, in much the same way as energy is stored in a spring or in raised weights when a clock is wound up. If the pendulum of the clock be started then the spring unwinds or the weights fall gradually, and the energy is expended in driving the clock. In the same way sending a current through a secondary battery stores up energy in it, and if the battery circuit be afterwards closed a current will be sent by the battery until such time as the circuit is broken, or the energy stored up in the cells has all been expended.

The first secondary battery of which we read consisted of two platinum plates immersed in dilute sulphuric acid (vitriol and water). When an electric current is passed from one plate of such an apparatus to the other oxygen gas collects on the first plate and hydrogen on the second; and if the plates be afterwards connected by a wire, a current passes through the circuit in an opposite direction to the initial current until such time as the gases disappear from the plates. If the platinum plates be replaced by lead ones, and a current is sent through the arrangement, the plate by which the current enters the liquid (the anode) darkens in colour, whilst the other plate (the cathode) becomes of a lighter grey than the original lead. These changes of colour are due to the surface of the anode becoming converted into peroxide of lead, whilst that of the cathode is converted into spongy metallic lead. The peroxidised plate is generally spoken of as the positive (+) plate, and the one coated with spongy lead as the negative (–). If the current be passed for some time and then stopped, the two lead plates in acid will act as a battery for a short period, until such time as the cell becomes discharged.

The amount of energy which can be stored up in two simple lead plates by a single charging is only small; but by repeatedly charging and discharging such plates and reversing the direction of the charging current occasionally, a considerable storage capacity may be attained.

The process of charging and discharging described above is generally known as "forming" the cells, and simple lead plate cells require a considerable expenditure of time and energy before they are fit for commercial use. To obviate this disadvantage,

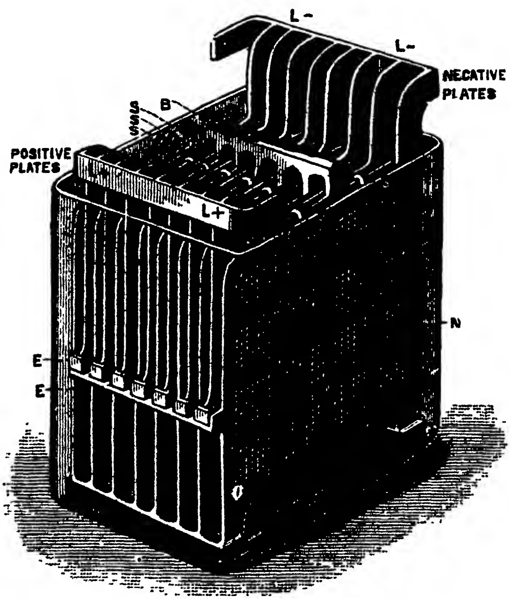


FIG. 1.—E.P.S. Cell, 1888 type.

Faure coated the lead plates with a paste made of red lead and sulphuric acid, thereby greatly reducing the time required to "form" the cells, and at the same time considerably increasing their capacity.

Most of the secondary batteries at present in commercial use are modifications of Faure's invention; great improvements have, however, been made in details of construction, which facilitate inspection and increase durability. Perhaps the greatest improvements are in the methods of preventing the paste from being easily detached from the plates. This is usually effected

by perforating the plates or making them in the form of "grids" and filling the spaces with the paste. Fig. 1 shows one form of cell having pasted plates, the white lines on the right-hand side of the plate N representing the grid, and the black spaces the paste or active material. It is now customary to make the grids of hard alloys of lead with other metals, such as antimony, to obtain greater rigidity.

Storage batteries are usually required to send large currents, and in order that the paste may not be disintegrated under

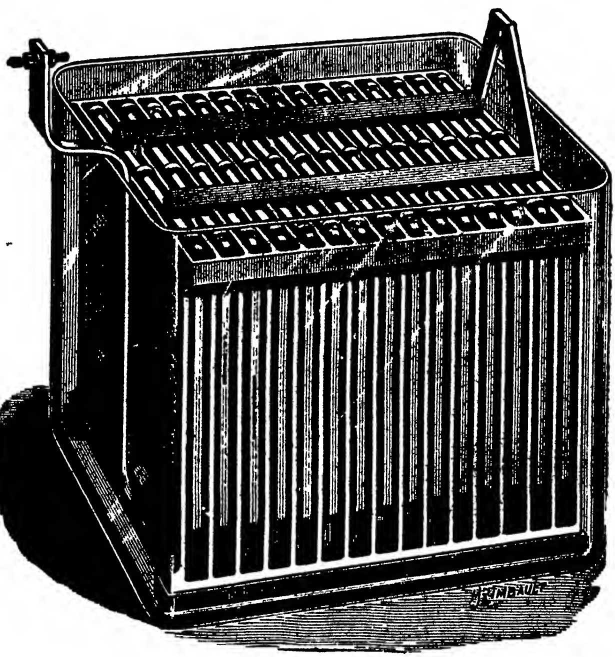


Fig. 2.—New "K" type of E.P.S. Cell (1891).

the action of the current it is necessary to have plates of considerable surface; about 30 square inches of positive plate surface per ampere* is the ordinary allowance. At this rate a cell required to discharge at 30 amperes would have 900 square inches of positive plate surface and a slightly greater surface of negative plate. Single plates of such large areas would be unwieldy, and so it is customary to join several smaller plates together as seen in Fig. 1, which represents a 15-plate cell

* The surface is reckoned by taking the area of both sides of the plate.

(7 positives and 8 negatives), having a capacity of 330 ampere hours. In this type of cell the two sets of plates are kept apart by ebonite or celluloid separators, S, S, S, &c.; and the positives rest on ebonite saddles, E, E, supported by a bar connecting the negatives together. The positives, as well as being joined to the lug L +, are connected together by a crossbar, B, by means of which they can be lifted out, and, as will be seen from the figure, each positive is between two negative plates. The distance between two adjacent plates is kept as small as possible consistent with allowing sufficient liquid to be between them, and permitting any plugs of paste which become detached from the grids to fall to the bottom of the cell. In recent cells this distance is about $\frac{3}{8}$ of an inch. An improved kind of pasted cell (Fig. 2), has lately been introduced, in which

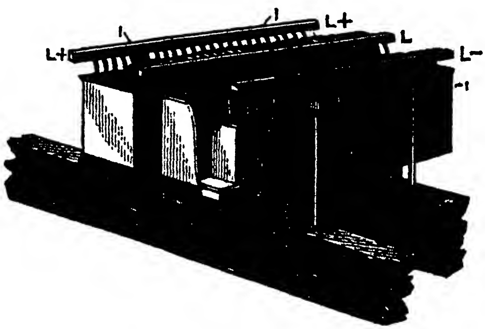


Fig. 3.—Crompton-Howell Cells.

the rate of discharge per square inch of plate has been doubled, about 15 square inches of positive plate per ampere being sufficient.

There are, however, cells with unpasted plates, such as the Crompton-Howell (Fig. 3), Elieson and Woodward cells, the latter of which is shown in Fig. 4. These possess the advantage that they can be discharged at a much greater rate per square inch of plate than those of the pasted type. The plates of the Crompton-Howell cell are cut from blocks of porous lead, and are "formed" by repeated chargings, dischargings, and reversals as previously described. The porous nature of the lead, however, enables the liquid to find its way within the plate, thereby greatly facilitating formation and increasing the useful capacity. These cells are frequently discharged at the rate of 1 ampere per 6

square inches of positive plate without serious damage. This is a great advantage in Central Station work, where the maximum demand for current lasts only a short time. In the recent types of Crompton-Howell cell, the plates are placed about half an inch apart, and are kept separated at the top by celluloid combs laid across the tops of the plates. The notches are only about ½ inch deep, and so practically the entire surfaces of the plates are freely exposed to the electrolyte.

Having seen how single cells are made, we must now consider the subject of connecting them together to form batteries.

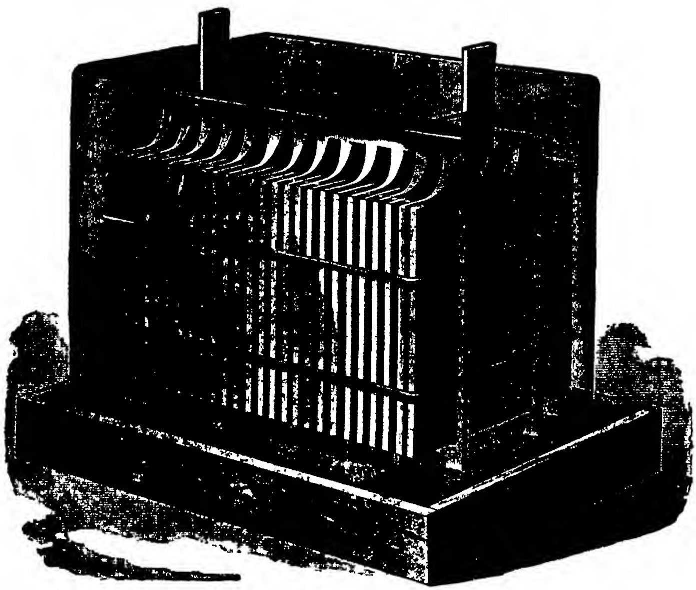


Fig. 4.—Woodward Cell.

There are two primary methods of connecting cells together, known respectively as the "series" and "parallel" arrangements. Combinations of these are sometimes used, but as they are described in Primer No. 5, on "The Arrangement of Batteries," we need not consider them in detail here. It will suffice to say that for lighting purposes, where the number of lamps is not large, the series arrangement is adopted, as illustrated in Figs. 3 and 8. In Fig. 8 it will be noticed that the negative plates of the first cell are connected to the positives of the second by means of the lugs and bolts; the negatives of the second are similarly joined to the

positives of the third, and so on. In the Crompton-Howell batteries the negatives of one cell and the positives of the next are attached to the same bar, L (Fig. 8); and these bars are carried by insulators, I, I. This construction reduces the re-

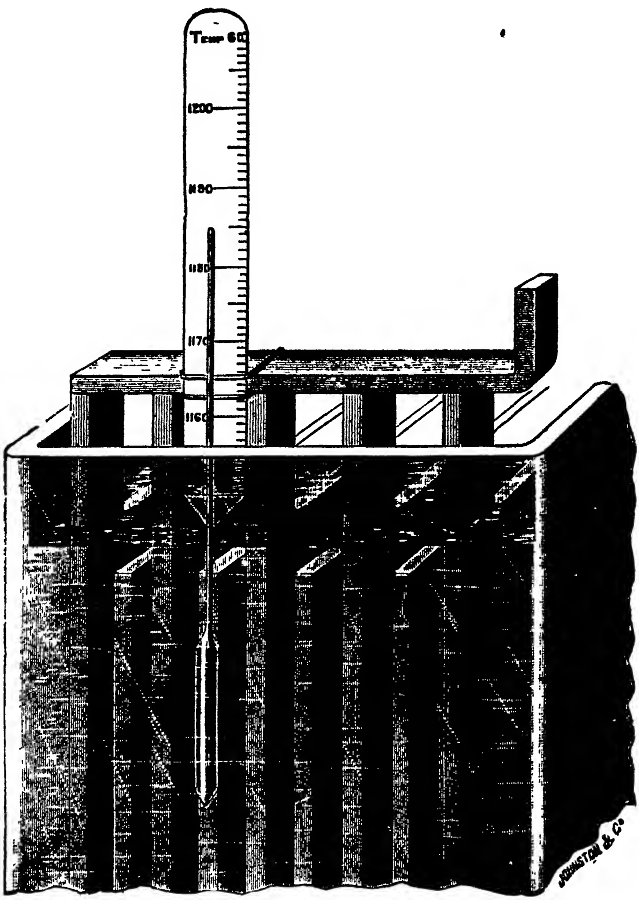


Fig. 5.—Holden's Hydrometer.

sistance of the connections to a minimum, and also permits any defective plate being removed and replaced without interfering with the working of the battery. By coupling together about 25 cells in either of these ways, sufficient electric pressure

may be obtained for working 50 volt lamps, for the electromotive force of each cell is about 2 volts, and $2 \times 25 = 50$. To facilitate connecting up, it is usual to paint the lugs on the positive plates red, and those on the negative black, so that for series arrangements a red of one cell must be connected to the black of the next. When cells are to be joined in parallel, the red ends must be connected together to form one terminal of the battery, and all the blacks connected together to form the other terminal. Care, however, should be taken not to allow cells to remain in parallel longer than necessary, for if one be defective all the others may be damaged.

Fig. 6.—Cell-testing Voltmeter.

The success or failure of a storage battery depends chiefly on the care and attention of the user and attendant; for an ill-used and neglected battery may be spoiled in a few months, whereas one carefully attended to may be kept in good working order for years. The two chief causes of trouble are excessive currents and prolonged discharges, and to keep a battery in good order it should never be completely discharged. In fact, it is usual to never utilize more than three-quarters of its total capacity. If a battery be run down too low, a white deposit of lead sulphate forms on the plates, and the cells are said to be "sulphated." When this has occurred the capacity of the cells is seriously

diminished and their resistance increased, both of which render them less valuable, and it is only by long continued chargings or by special means that the sulphate can be removed. Even when this has been done, the positives are generally left in a very brittle state, and in some cases gradually crumble to pieces. The effect of excessive currents is to loosen the plugs of paste; these eventually drop out, and may lodge between the plates and discharge the cells. Sometimes the plates bend or buckle, and come into contact, with similar results. The ordinary working currents occasionally produce the same effect, and to keep cells in order it is necessary to keep a watch over each, and to remove any defect as soon as possible.

FIG. 7.—Hick's Bead Hydrometer.

The condition of any cell can be tested, either by a hydrometer (Fig. 5) or by a voltmeter (Fig. 6). The former shows the density or heaviness of the liquid, and the latter the electric pressure which the cell produces. Both these fall as the cell discharges and rise during charging, so that their indications give an idea of the state of the cell. The voltmeter method is, perhaps, the best when the cells are in work, but the hydrometer is most reliable for cells standing idle; this arises from the fact that the electromotive force of an idle cell does not vary much with the charge it contains.

Another form of hydrometer (Fig. 7) shows the approximate density by the number of the beads floating, for they are made so that one floats when the density is 1,150, two when it becomes 1,170, three when it is 1,190, and four when it arrives at 1,200. A density of 1,200 (water at 60° F. being taken as 1,000) is the normal density for fully-charged cells of the E.P.S. type. When this density is reached the cells usually begin to give off gas freely, and the liquid appears milky. In the Crompton-Howell cells, however, it is customary to use stronger acid, the working density varying from about 1,240 to 1,260.

So much has been said of the difficulties to be met with in the use of secondary batteries that it appears desirable to now

refer to their advantages. First and foremost among these may be placed the readiness with which a current may be obtained; for, from a charged battery, current is instantly available at any time, without the trouble of either setting up primary batteries, or getting up steam or starting a gas engine to drive a dynamo. Secondly, the currents from storage cells are steady, and not subject to fluctuations such as must occur in currents from dynamos, or to the rapid falling off which usually takes place in currents from primary cells. Thirdly, by means of a few storage cells joined in parallel, currents of great strength can be readily obtained, which, otherwise, would require an enormous number of primary cells or a very large dynamo. Fourthly, their low internal resistance renders them particularly useful as regulators to steady the fluctuations in the currents from dynamos driven from gas engines or badly governed steam engines. Fifthly, installations fed from accumulators are practically self-regulating over a considerable range of current; for, owing to their low resistance, the pressure at the terminals is nearly independent of the number of lamps alight. Another advantage occurs in electric distribution (*see* Primer No. 34, on "Systems of Distribution").

As mentioned above, the pressure at the terminals of a secondary battery rises as the charging proceeds and falls during the discharge. The variation is usually 10 to 15 per cent. with pasted plate cells, but may be greater with the unpasted type on account of the greater rates of charge and discharge allowed. If, therefore, the pressure on the lamps is to be kept fairly constant, some method of regulation is necessary. This is generally effected by regulator cells and switches, arranged so that the number of cells on either the lamp or dynamo circuit may be varied. Fig. 8 shows a complete arrangement of cells, switches and dynamos. In this it will be seen that the current may pass from the + terminal of the dynamo directly to the lamps, and also through the discharging current alarm to the + pole of the battery. The negative end of the dynamo is joined through the charging main and regulator switches to the junction of the second and third cells from the negative end of the battery. The same junction is also connected through the discharging regulator and main switches to the other ends of the lamps. Thus the two right-hand cells are out of circuit entirely. This condition of affairs would exist when the dynamo was running and all the cells

nearly charged. If, now, the charging was stopped, the pressure between the lamp terminals would fall; and to restore it to

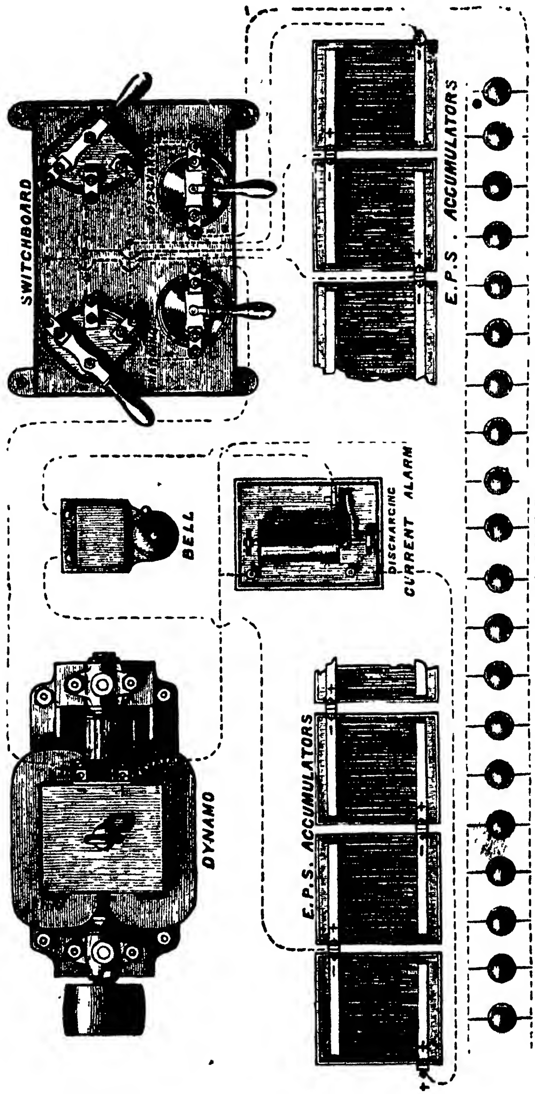


FIG. 8.—Arrangement of a Lighting Installation.

its former value it would be necessary to switch in, say, one more cell by lifting the handle of the right-hand regulating

switch until it is horizontal. As the cells become discharged the remaining cell must be switched in. It will be noticed that the two right-hand end cells get used less than the others, and, consequently, require less charging; for this reason the left-hand regulating switch is provided so that either one or both may be cut out of the dynamo circuit when they become milky before the rest.

The discharging current alarm and bell shown in the figure are to give warning when, from any defect in the dynamo's working, the cells begin to discharge instead of being charged.

656 Pages. 397 Illustrations.

A DICTIONARY

OF

Electrical Words, Terms, and Phrases.

BY

Prof. EDWIN J. HOUSTON, A.M.

THIS Dictionary contains close upon 2,500 distinct Words, Terms, or Phrases, and has been brought up to date by means of an Appendix, in which are placed the very newest words, as well as many whose rareness of use had consigned them to obscurity and oblivion.

LINES OF FORCE.

THE action of magnets upon each other is generally described as being due to attractions and repulsions exerted between their poles across the intervening space. There is, however, another way of regarding the effects which it is far more useful to consider.

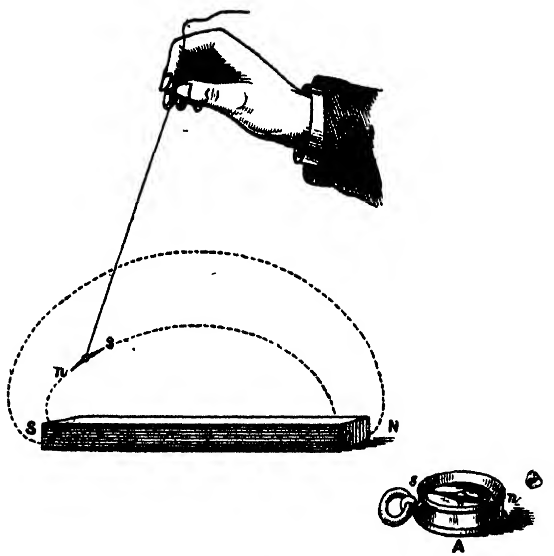


FIG. 1.

According to this view the force exerted on the pole of a magnet is dependent simply on the state of the surrounding medium, and has no direct connection with the strength of other magnetic poles at a distance from it, although this may be the cause of the magnetic state of the neighbourhood. If, as in Fig. 1, a small needle, *n s*, suspended by a thread and capable of free movement,

or balanced on a needle point in a closed case, A, is held near a magnet, N S, it will point in some fixed direction dependent on the proximity of the poles of the bar magnet. The direction taken up is called the direction of the force at the point, and if the suspended needle be moved forward in the direction of the pole *n* it will trace out a curved line, which will be found to start from one of the poles of the bar magnet and end in the other. Such a line is said to be a *line of force*, and it is such that its direction is always the same as that of the magnetic force exerted by the magnet, N S, on a North pole placed on the line. The space filled by these lines of force is called the *magnetic field*.

A much more convenient method of showing the direction of these lines than the one we have just described is by means

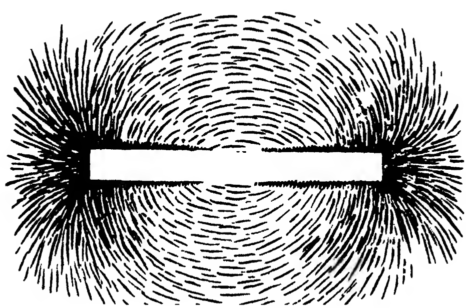


Fig. 2.

of iron filings. A small piece of soft iron, whether previously magnetic or not, becomes magnetised when placed in the neighbourhood of a magnet; and it may be made to act in the same way as the suspended needle, *n s*, provided it be sufficiently free to move. The necessary freedom can be imparted by simply tapping the surface on which the iron filings rest, since any force tending to turn them will be able to exert itself before the filings take up their new position of repose. If, therefore, a piece of stiff white paper be strewn evenly with iron filings, placed in any magnetic field, and gently tapped, the filings will arrange themselves so as to show the direction of the lines of force. Fig. 2 shows the appearance presented by placing the paper over a bar magnet (whose position is indicated by the blank rectangle), and Figs. 3, 4, 5, 8, and 9 show the use of the

method for investigating magnetic fields of various kinds. The process makes the lines of force to appear most crowded together

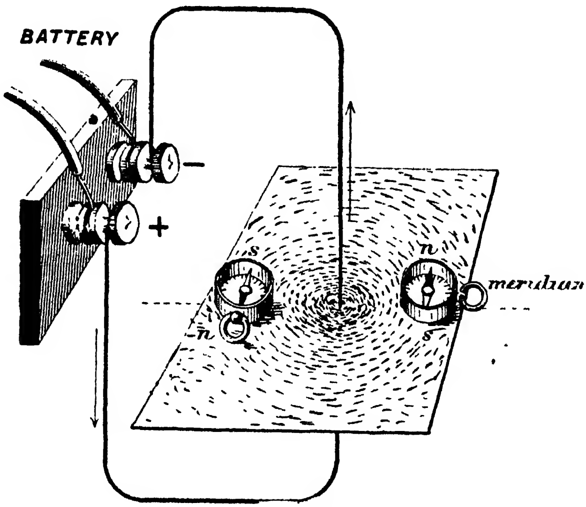


Fig. 3.

where the iron filings have been most thickly strewn, and in this respect it is imperfect, because lines of force can be drawn so

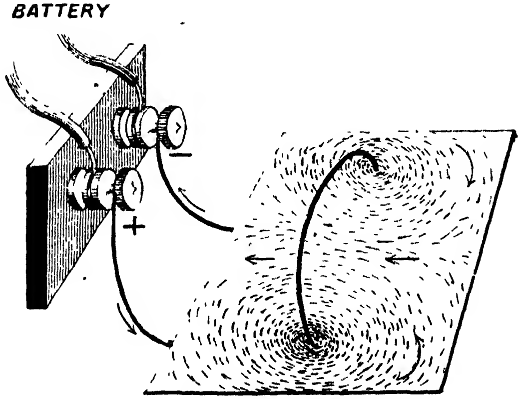


Fig. 4

that not only does the direction of the line represent the direction of the magnetic force but also so that the density of the lines at

any given place exactly represents the magnitude of the force at that place. The lines of force will be very crowded near the poles, where the force is most intense, and will be very sparsely

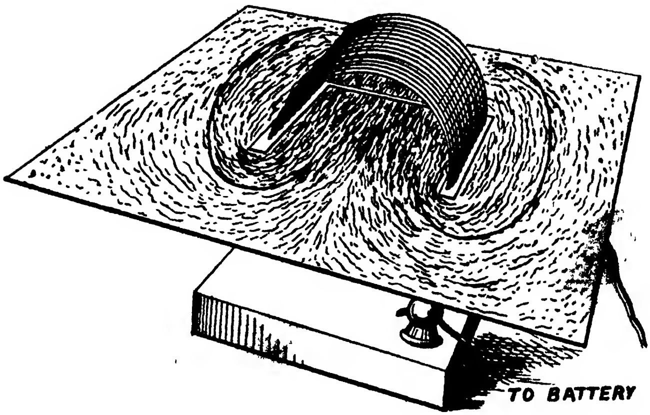


FIG. 5.

distributed at a distance, where the force is small. It is owing to this possibility of completely representing all the

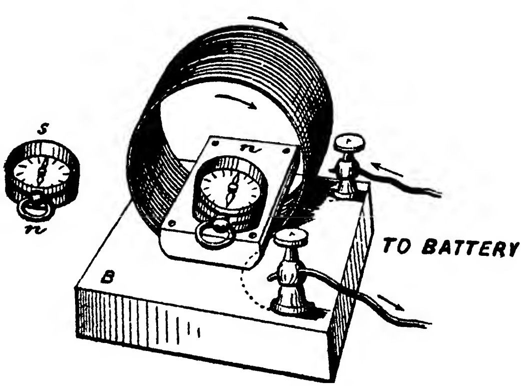


FIG. 6.

properties of a magnetic field that lines of force are of so much importance in electrical engineering, where quantitative results have to be considered.

The most fundamental property of an electric current is its power of exerting magnetic force, or, in other words, its power of creating lines of force around it. Fig. 3 shows how the lines arrange themselves around a conductor carrying a current. The dotted circular lines of filings exhibited on the card-board sheet show that the lines of force due to the current are concentric circles in a plane at right angles to the wire. Fig. 4 exhibits what happens when the current passes through the sheet up on one side and down on the other. The lines, as before, are densest near the wires, but they all flow through the loop, around the wire, and ultimately back again through the loop, re-entering on their former course. Each line forms a closed ring, and this is a most important property universally possessed by lines of force. If a coil or solenoid is formed, as in Fig. 5, of many turns, the magnetic force is more intense, but

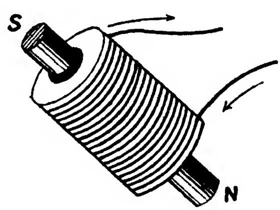


Fig. 7.

the general direction of the lines remains the same, and little suspended magnets placed within and without the solenoid, as in Fig. 6, will show that the magnetic force is in opposite directions, as indicated by the direction of the lines in Fig. 5. If, now, a bar of some magnetic substance like iron be placed within the solenoid, as in Fig. 6, the magnetic force exerted in the neighbourhood—*i.e.*, the density of the magnetic lines—will be much increased although the magnetising current remains unaltered. Such an arrangement is called an electro-magnet, and the strongest magnets known are produced in this way. The core of the electro-magnet may be straight and surrounded by a simple solenoid, as in Fig. 7, but more usually is bent into a horseshoe shape, with a magnetising coil on each limb, as in Fig. 8. This diagram also shows the iron filing curves, denoting the direction of the magnetic lines, and, by comparison with Fig. 9, which represents the same electro-magnet with a bar

of soft iron near the poles, the effect of introducing a bar of magnetic material into the field may be observed. It will be noted that the lines seem to be drawn into the bar, whose posi-

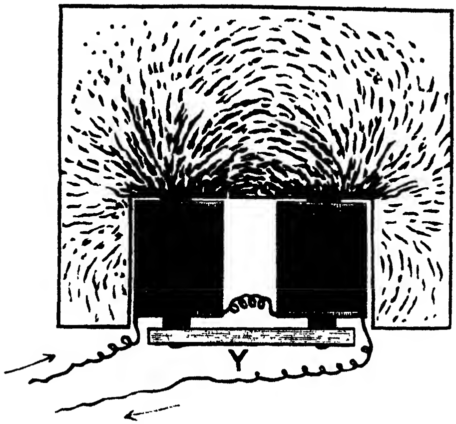


FIG. 8.

tion is indicated by the blank space among the lines, and instead of spreading out into space tend to shorten themselves by passing through the iron. The iron, in fact, shields the external medium

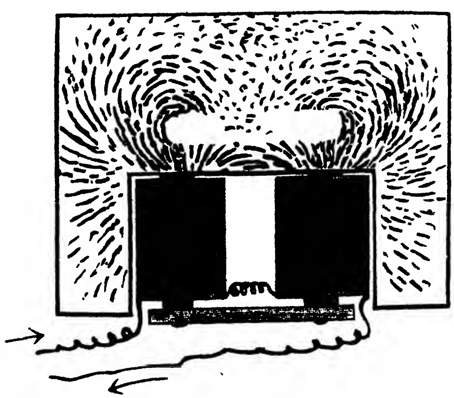


FIG. 9.

somewhat from the magnetic force exerted by the poles, and when it is allowed to approach the poles very closely this effect may be so marked that no appreciable magnetic force can be detected

except quite close to the iron. Lines of force, in fact, always tend to shorten themselves and pass through the iron, because by so doing the length of the circuit through the cores of the electro-magnet, and the medium between the poles is diminished.

Whenever, as in dynamos, a great number of lines of force are required in a given space, the iron core, with its surrounding magnetising coils, should be bent round in as short a circuit as possible until its ends border the space in question. Thus, in Fig. 10, which represents one form of dynamo, the field-magnet, F, has its core solid and in the form of a continuous ring, except

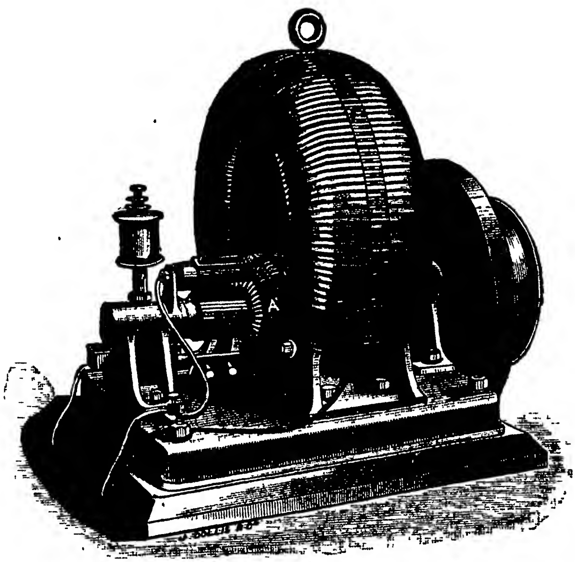


Fig. 10.

at the gap, where the armature, A, of the dynamo is placed, and where the lines of force are needed. Straying of the lines into the air surrounding the dynamo is to be prevented as much as possible, since such waste lines serve no useful purpose. For permanent magnets these considerations do not hold, for the object of such magnets is to produce magnetic force *at a distance*, and this can only be the case when the lines of force stray out from the poles. It is, moreover, necessary to shape the magnets so that the magnetism will be permanently retained. Only a portion of the magnetism produced by a current remains after the

current ceases to flow, and although a short, thick, continuous ring of iron requires the least magnetising force to produce a given number of lines, the best form of magnet to *retain* its power is one whose limbs are long and thin. Permanent magnets are, moreover, always made of the hardest possible steel, for although soft iron is the easiest substance for lines of force to penetrate, it is also the substance which easiest loses its magnetism, while hard steel retains magnetism very well, although it is much more troublesome to magnetise. Permanent magnets were at one time used for dynamos; but the density of lines of force easily obtainable in soft iron by a magnetising current is more than ten times as great as the magnetic density in the best permanent magnets of suitable size, and the use of the latter for such purposes has long since been abandoned.

The following book may be recommended to those wishing to gain further information on this subject :—

"Practical Notes for Electrical Students." Vol. I. By A. E. Kennelly and H. D. Wilkinson.

The Electrician" Primers.—**No. 9.**

MAGNETS.

A MAGNET is a body which will attract iron, and which, when pivoted so that it can move horizontally, will take up a certain definite N. and S. position, and when pivoted so that it can move vertically will take up a certain definite inclined posi-

FIG. 1.

tion. Although most substances exhibit magnetic properties, iron and steel are the only two metals one need consider in practice, since their magnetisability is so enormously greater than that of any other known substance.

Magnets may be broadly divided into two classes, namely, *permanent magnets* and *electro-magnets*, or, more correctly speaking, temporary magnets. Permanent magnets are usually of hard steel,

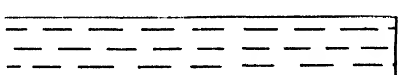


FIG. 2.

while electro-magnets are best made of the softest iron. Permanent magnets are those which permanently retain a certain amount of magnetism even after the magnetising force has been removed. Electro-magnets, on the other hand, become practically non-magnetic under such circumstances.

The difference in the behaviour of iron and steel in this respect is explained on the assumption that each individual particle or molecule is a little magnet. In the ordinary state of the metal the particles are thought to be arranged in a haphazard way, as shown in Fig. 1. When a magnetising force is applied, it is supposed that all the particles swing round so as to form long chains, as shown in Fig. 2, and this orderly arrangement is supposed to constitute magnetisation, the centres of external magnetic activity, called the *poles*, being situated at or near the ends. One pole, marked N in the figure, which is called the North pole, points North when free to move, and the other, marked S in the figure, points to the South. When two magnets, free to swing, are brought near to each other, it is observed that a North pole will repel a North pole and attract a South pole, and *vice versa*. Hence the law, *like poles repel each other, unlike poles attract each other*. Now, to return to the theory of magnetism, in steel it is imagined that the particles are less free to move than in soft iron. Hence a greater magnetising force is required to attain a given degree of magnetisation with a steel bar than with an iron bar. But as the particles of steel when once rotated are more or less constrained, almost all the magnetisation induced permanently remains. This characteristic of retaining magnetism is called *retentivity*.

Bars of iron or steel may be made magnetic by simply stroking them with already magnetised bars, but the most effectual method is to place them within a coil, such as the one shown in Fig. 3, and to pass an electric current through the coil. A wire conveying an electric current, as has already been stated in these Primers, is surrounded by a magnetic whirl and the lines of force pass through the bar, as shown, making it magnetic.

If we denote by **H** the strength of the magnetising force (*see* Fig. 3), or, in other words, the number of lines of force per square centimetre,* flowing through the coil *before* a bar is inserted in it, and by **B** the strength of the magnetism induced in the bar, or, in other words, the number of lines of force per square centimetre existing *after* the bar is introduced, then the ratio of **B** to **H** is termed the *permeability* of the sample and is denoted by the Greek letter μ. Since $\frac{\mathbf{B}}{\mathbf{H}} = \mu$, it is obvious that $\mu\mathbf{H} = \mathbf{B}$; that is to say, when we speak of the permeability of a certain piece of

* 1 square centimetre = ·155 sq. inch. 1 square inch = 6·45 sq. centimetres.

iron or steel we mean the number of times by which its insertion in a coil multiplies the magnetising lines of force previously existing there. The value of μ not only varies for different samples but for the same sample according to its magnetic state, its value becoming less and less as more and more lines are forced through. Thus, in soft iron, when **B** is, say, 12,000, μ is 2,400 ; but when **B** is 17,000, μ is only about 300; in other words, the sample is becoming *saturated* with lines of force and

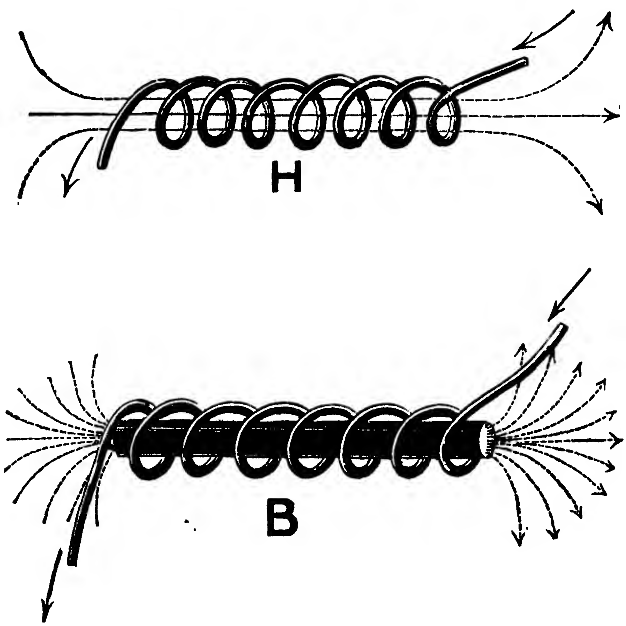


Fig. 3.

can take no more without difficulty. The practical limiting value for **B** is, in the case of good wrought iron, 20,000, and in cast iron 12,000. This phenomenon of saturation is shown by the curves in Fig. 4, where the values of **H** are marked along the horizontal line, and the corresponding values of **B** for each sample are marked along the vertical.

Magnets are made in all shapes and sizes, from the little diamond-shaped needle one sees in compasses to the peculiar looking field-magnets, weighing several tons, employed in large

dynamos, of which Figs. 5—8 are examples. Permanent magnets had their first use in the compass, and then in connection with telegraphy and telephony. Electro-magnets were mainly

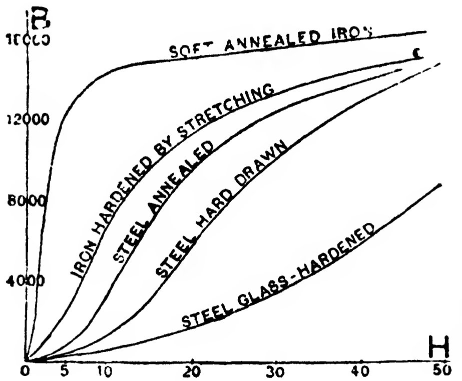


Fig. 4.

scientific toys until the invention of the modern dynamo machine. Quite recently a new and promising field of usefulness has been opened to electro-magnets in connection with the sifting of iron

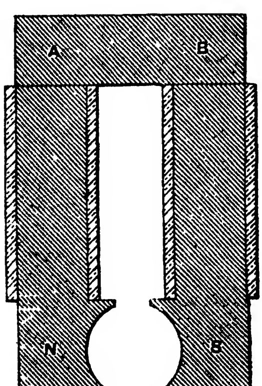


Fig. 5.—Edison-Hopkinson Dynamo.

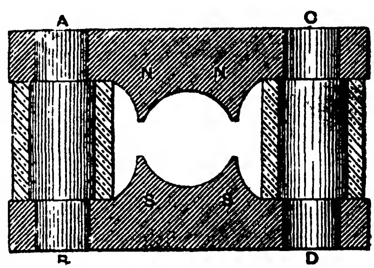


Fig. 6.—Manchester Dynamo.

filings from the sweepings of machine shops and in separating iron ores. Perhaps the very latest application is that just made in America, where a huge overhead bell-shaped electro-magnet is

employed to pick up heavy castings in some Pittsburg ironworks, and carry them about as required.

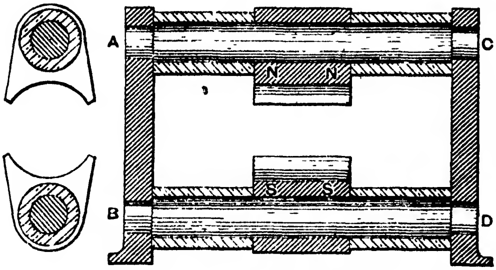


FIG. 7.—Goolden and Trotter Dynamo.

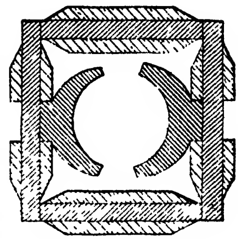


FIG. 8.—Elwell-Parker Dynamo.

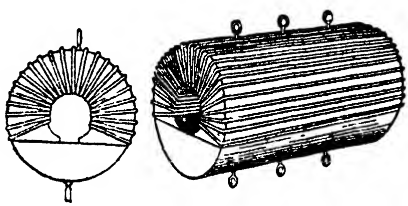


FIG. 9.

An electro-magnet of the curious but efficient shape shown in Fig. 9 was designed some 50 years ago by Joule for this very purpose of lifting heavy weights.

The following books may be recommended to those wishing to obtain further information on this subject:

"The Electro-magnet." (Cantor Lectures.) By Silvanus P. Thompson.

"Elementary Lessons in Electricity and Magnetism." By Silvanus P. Thompson.

"Elementary Manual of Electricity and Magnetism." By Andrew Jamieson.

"The Electrician" Series.

SECOND EDITION.

ELECTRO-CHEMISTRY

(INORGANIC).

By GEORGE GORE, LL.D., F.R.S.

THIS book contains, in systematic order, the chief principles and facts of Electro-Chemistry, and is intended to supply to the student of Electro-Plating or Electro-Metallurgy a scientific basis upon which to build the additional practical knowledge and experience of his trade.

"The Electrician" Primers.—**No. 10.**

ELECTRICAL UNITS.

Every quantity has to be measured in terms of some fixed unit quantity of its own kind. Thus we may measure the length of a rod in inches or centimetres, or in terms of some other unit of length. The unit adopted may be chosen in the first instance in a purely arbitrary manner, or so that it is connected in a simple way with units of another character. The yard and most of the old English measures are quite arbitrary, while the metre is a related unit, since it is a certain fraction of the length of a parallel of latitude taken through Paris. The French unit of mass is another example of a related unit, since it is the mass of a cubic centimetre of water at standard temperature and pressure. Electrical units are all of this character, each one being connected in a more or less direct manner with the French units of length, mass, and time, *i.e.*, the centimetre, gramme, and second. It is beyond our present purpose to enter into the considerations which have guided electricians in the choice of the units which they have adopted. It will be sufficient for us to give the names of the principal units, and illustrate their meaning by reference to examples.

The unit of current strength is called the *ampere*. This is about the current required to make ordinary glow lamps bright, although the amount varies, according to the thickness of the filament of the lamp, from one-third of an ampere to 3 amperes. Bernstein lamps require 8 to 10 amperes, and Sunbeam lamps, which are very large incandescent lamps, require from 10 to 20 amperes. The current required for arc lamps, except those of very great illuminating power, varies from 10 to 20 amperes, according to the thickness of the carbon. The human body is a conductor, and will, therefore, permit electricity to pass through

it, but a current as much as one ampere, if passed through the body, is dangerous. The heating of a wire depends on the number of amperes passing through it and on the section and material of the wire. It does not depend on its length or on the character of the rest of the circuit.

The unit of electrical pressure, potential or electromotive force, is called the *volt*. This is nearly the electromotive force of a Daniell cell. A Leclanché cell gives about $1\frac{1}{2}$ volts, while a Grove cell, or an accumulator, yields about 2 volts. The number of volts, or voltage, required to work an arc light rarely falls below 60, but a glow lamp, according to the length of its filament, may require any voltage from 3 or 4 up to 100, or even more. Dynamos for lighting purposes are generally designed to produce electricity at constant pressure, although the current taken from any one may vary greatly according to the number of lamps required at any particular time. It is exceedingly important that the regulation should be good, for otherwise the lamps will fluctuate in brightness, and wear out sooner. There are, however, cases in which it is desirable to distribute electricity with a constant current. The lighting of arc lamps is generally done on the series system, *i.e.*, with the lamps arranged one after the other along the same wire, for, since each lamp takes 10 or more amperes, if 50 were worked in parallel, *i.e.*, arranged on separate wires branching across the main leads, the current would necessarily be very large, and would require heavy and expensive leads. For such purposes a constant current dynamo is needed, giving about 10 amperes under all circumstances, the voltage rising as the number of lamps in circuit increases.

The unit of resistance is called the *ohm*. It is such that a conductor whose resistance is one ohm will require an electrical pressure of one volt at its terminals to drive a current of one ampere through it. The number of volts, V, required to cause a current of A amperes to flow through a conductor whose resistance is R ohms, is obtained by multiplying A by R, thus $V = AR$. The resistance of a mile of copper wire one-tenth of an inch in diameter is about 3 ohms. The standard ohm is a column of mercury of 1 square millimetre cross-section and 106·3 centimetres long, at a temperature of 0°C.

The electrical power supplied by a dynamo or any source of electrical energy is measured by the product of the current and the voltage at which it is supplied. The unit of power is thus a volt-ampere, and this is called a *watt*. A horse-power is equivalent

to 746 watts. A dynamo which works at 80 volts pressure, and yields a current of 400 amperes, supplies energy at the rate of $80 \times 400 = 32{,}000$ watts, and produces electrical energy at a rate corresponding with 43 horse-power. Electricians have adopted 1,000 watts as a commercial unit of power, and the above dynamo would be technically described as a 32-unit machine. Since the number 746 is very nearly 750, the horse-power of any dynamo can be obtained from the number expressing its power in electrical units by simply adding one-third; thus, $32 + \frac{1}{3}(32) = 43$ horse-power. The horse-power required for lighting a given number of lamps may be obtained by multiplying the number of lamps by the voltage and current absorbed by each, and dividing the result by 746. Ordinary glow lamps of 16-candle power absorb about 60 watts each, so that 40 of them would require 2,400 watts, or 3·2 horse-power. Fifty arc lights, each taking 15 amperes at 60 volts pressure, require $50 \times 15 \times 60 = 45{,}000$ watts, or 60 horse-power.

The watt is a unit of power, not of energy. Electricians have adopted the watt-second, or *joule*, as the unit of energy. The practical unit is, however, much larger, and is equal to 1,000 watt-hours. This amount of energy is adopted as the Board of Trade unit, and when it is stated that an electrical company supply energy at the cost of 8d. per Board of Trade unit, it means that they are willing to supply at the rate of 8d. for every $1\frac{1}{3}$ horse-power hour, or 6d. per electrical horse-power per hour. At this rate, the cost of running the 50 arc lights above mentioned would be 30s. per hour, and the 40 glow lamps would cost 1s. 7d. for the same time, or about one halfpenny each per hour.

Many other electrical units have been named, but those already mentioned are the ones chiefly used in practice. The prefixes milli, micro, and meg, denoting respectively thousandth, millionth, and million, are sometimes used in connection with the units to save the need of using numbers containing many figures. Thus a milliampere is one-thousandth of an ampere, a microvolt is a millionth of a volt, and a megohm is one million ohms. Insulation resistances are generally reckoned in megohms because they are always large, while the currents used in telegraphy would be most conveniently expressed in milliamperes, owing to their minuteness. Instruments intended for the measurement of electrical quantities are generally named after the unit in which they express the measurement; thus, a voltmeter is an instrument for measuring volts, an ammeter

measures amperes, and a wattmeter watts. An ohmmeter is a special instrument for measuring resistance, while a coulombmeter measures electrical quantity in coulombs.

We tabulate below the chief electrical units :—

The ampere	is the	unit of	current.
,, volt	,,	,,	pressure or potential.
,, ohm	,,	,,	resistance.
,, watt	,,	,,	power.
,, joule	,,	,,	energy.

1 horse-power = 746 watts.
1 commercial unit (power) = 1,000 watts.
Board of Trade ,, (energy) = 1,000 watt hours.

The following books may be recommended to those wishing to gain further information on this subject :—

"Units and Physical Constants." By J. D. Everett.

"Absolute Measurements in Electricity and Magnetism." By Andrew Gray.

"Elementary Lessons in Electricity and Magnetism." By S. P. Thompson.

THE GALVANOMETER.

Most of us know that a suspended magnet or a compass needle tends to set itself in a particular direction. If a wire, through which an electric current is flowing, is brought near such a magnet, the latter is usually caused to point in some other direction, and is said to be deflected from its initial position. If now the wire be kept still and the current through it increased, the amount which the needle is deflected will also be increased, whilst a diminution in the current causes a decrease in the deflection. It will thus be seen that the deflection of the magnet depends on the strength of the current in the wire, and may thus be used to measure the current. Instruments based on the above principle are called galvanometers.

Perhaps the simplest kind of galvanometer is made by suspending a piece of magnetised knitting needle *above* a wire laid on a board, as in Fig. 1. A circle may be drawn on the board and divided so as to enable us to see how far the needle is deflected. By attaching a battery so that a current flows in the way indicated by the arrow, then the needle will be deflected in the direction shown, and if the current be very strong the needle will set itself nearly at right angles to the wire. A pivoted compass needle placed above the wire would act in a similar manner. Such a galvanometer as the one described above would only be suitable for fairly large currents, such, for example, as are used in incandescent lamps of 10 to 20 candle-power. If we wish to measure much smaller currents—such as are sent along telegraph wires—we require to make the instrument more sensitive. This may be done in a variety of ways. One way of increasing the sensitiveness is to bring the needle as near to the wire as possible without touching it, and another to wind the wire so that it passes under the needle a number of times instead of only once, before being connected to

the battery; this is shown in Fig. 2. Still greater sensitiveness may be obtained if instead of having the parts of the wire *b* far away from the magnet, we put them near the magnet but *above it*; for a current flowing *below* a magnet in one direction tends to deflect it in the same way as a current *above* the magnet in an opposite

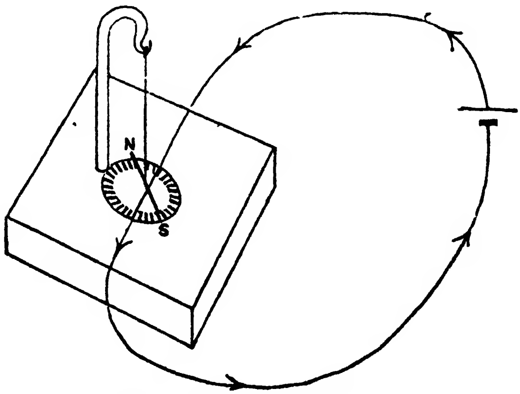


FIG. 1.—Simple Galvanometer with single wire.

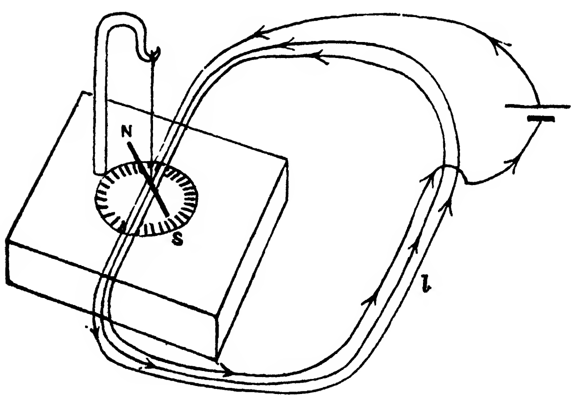


FIG. 2.—Simple Galvanometer with three wires.

direction. Fig. 3 shows an apparatus by which the latter statement may be proved; for a current sent along *a b* deflects the needle N S in the same direction as a current along *c d*. We have thus arrived at a form of galvanometer shown in Fig. 4, in which a magnetic needle, N S, is surrounded by a coil of wire,

and this is a type of instrument in very common use. In many cases the coil is made in two parts, and the needle placed between them. This arrangement is adopted in the instrument shown in Figs. 5, 6, and 7. In Fig. 6, one of the parts has been removed so as to show the needle N S in position ; the needle itself is shown separately in Fig. 7, whilst Fig. 5 shows a front view of the complete instrument. If the galvanometer is required to measure fairly large currents, then the coil may have only one or

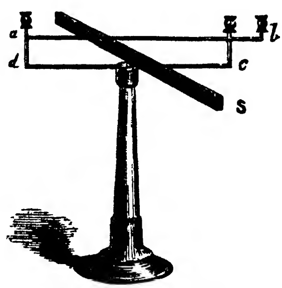


FIG. 3.—Oersted's Apparatus.

two turns of wire in it, whereas for small currents the wire has to be wound round the needle a great number of times in order that a fairly large deflection may be produced.

Another method of making a galvanometer more sensitive is to use two magnets fixed together, parallel to each other, so that the North pole of one is opposite the South pole of the other, as shown

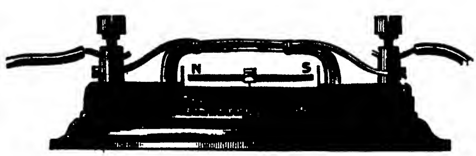


FIG. 4.—Simple Needle Galvanometer.

in Figs. 8 and 9. Such an arrangement is called an *astatic needle*. The advantage of it arises from the fact that its tendency to set north and south is much less than that of a single magnet ; for both N and N′ would, if the magnets were separate, point north, so that the tendency of the arrangement is the difference between the tendencies of each magnet separately. When using an astatic needle care must be taken to place the coil in such a position that the current deflects the two magnets in the same

direction. This, however, is easily done by putting one of them inside and the other outside the coil. This arrangement is shown in Fig. 8, where the line round the lower magnet indicates the position of the coil. Another method is shown in Fig. 9, where

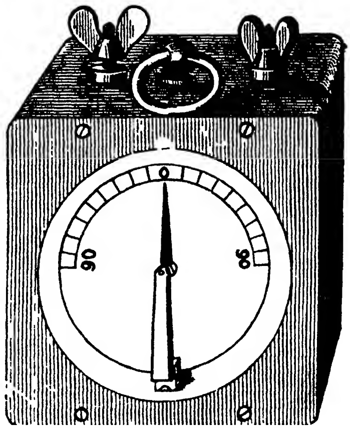


FIG. 5.—Lineman's Detector.

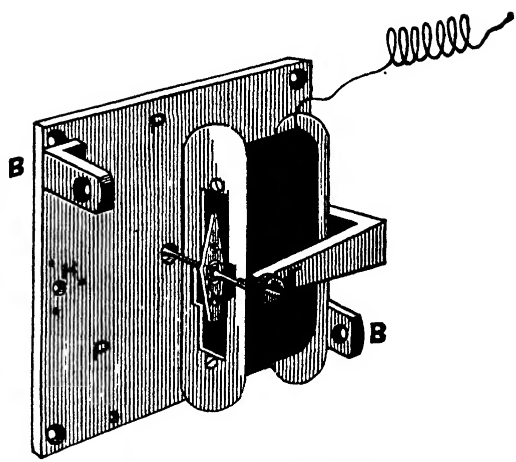


FIG. 6.—Interior of Detector.

each needle is placed within a separate coil. Fig. 10 shows a complete galvanometer made on the principle above described.

Before a galvanometer can be used to measure (not merely indicate) currents, it is necessary to know how the deflec-

tion varies with the strength of current passing through the galvanometer; in other words, the galvanometer must be *calibrated.* This may be done by sending various currents through the galvanometer and noting the deflections they produce;

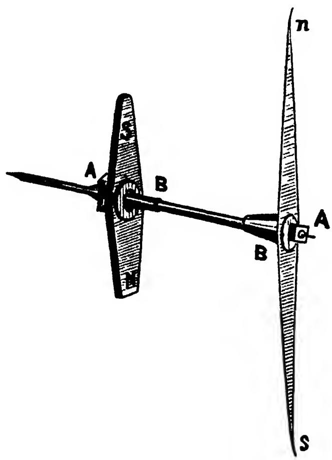


FIG. 7.—Needle and Axis of Detector.

the strength of these currents may be measured by a standard galvanometer, or by some other method that need not be described here. Of course, if it is only necessary to know whether one current is greater or less than another, there is no necessity

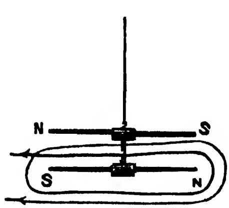


FIG. 8.—Astatic Needle with One Coil.

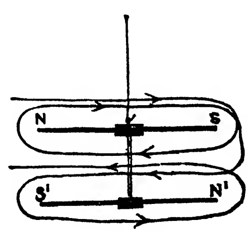


FIG. 9.—Astatic Needle with Two Coils.

to calibrate the galvanometer, for we may be sure that a current which produces a deflection of 20 degrees is greater than one which produces a deflection of 10 degrees on the same galvanometer; on the other hand, we could not say *how much*

greater was the first than the second unless we knew something about the calibration of the instrument. Generally, however, we may say the deflection of a galvanometer increases as the current

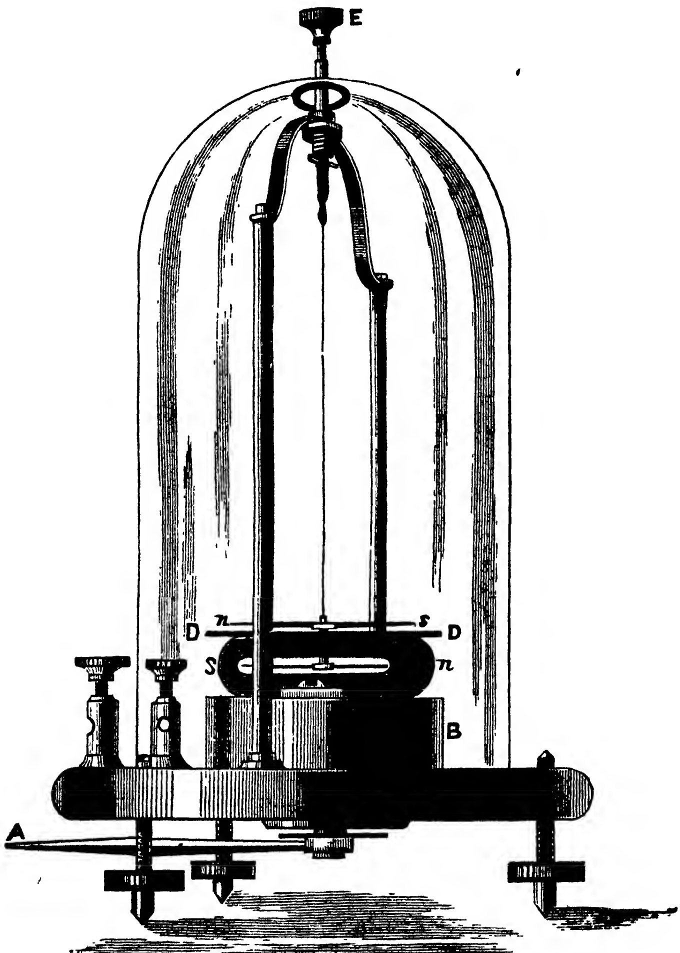


Fig. 10.—Astatic Galvanometer.

sent through it increases, but that the two do not usually increase in the same proportion.

The general principle of galvanometers having been explained, we may now indicate the various types of instrument in common

use which have not been referred to above. First and foremost amongst them is the "tangent galvanometer," so called because the tangents of the angles of its deflections are proportional to

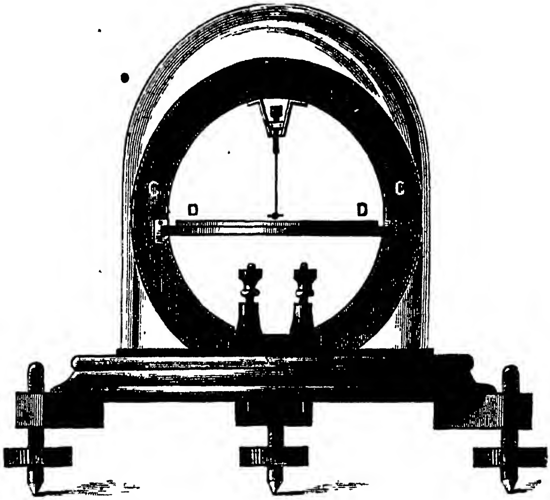


FIG. 11.—Tangent Galvanometer.

the currents causing the deflections. This consists of a large coil and a short needle. One form is shown in Fig. 11, and another in Fig. 12, the coils being marked C. In these in-

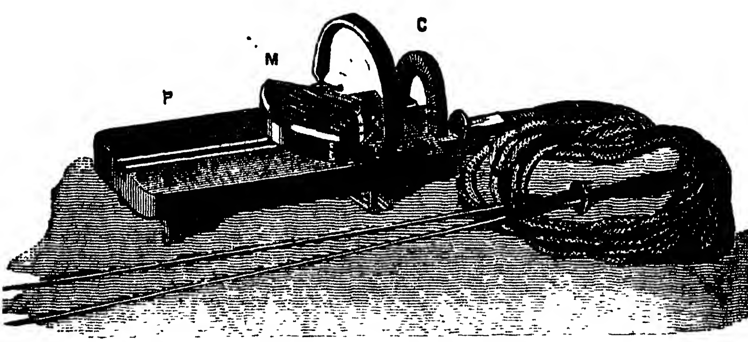


FIG. 12.—Thomson's Graded Tangent Galvanometer.

struments the needle N S is so short that it is unsuitable to read the deflection by, consequently a light pointer is usually attached to it for this purpose. The importance of the tangent galvano-

meter arises from the fact that the relation between the deflection and the current can be determined by calculation, and hence it may be used to measure currents without being calibrated experimentally. It is also useful as a standard galvanometer by means of which others may be calibrated.

Tangent galvanometers are usually unsuitable for measuring very small currents, owing to the fact that the wire is at a considerable distance from the needle, and this constitutes one of the chief disadvantages of the instrument. This defect may be somewhat minimised by using a very long pointer, so that its end may move a long distance for a slight deflection. But although such a pointer may be used, it causes the needle to swing very slowly, and consequently it requires a long time to take a reading. To overcome this difficulty Sir W. Thomson, instead of using a long pointer, attached a small piece of thin looking-glass to the needle. A ray of light reflected from this mirror to a sheet of ruled paper serves to show a very slight angular movement of the needle, just in the same way as the reflection from a piece of looking-glass held in the sunshine can be made to travel a long distance by a comparatively small turn of the hand. This principle of magnifying small motions is used in nearly all the most sensitive galvanometers, and such instruments are called reflecting galvanometers.

Although mirrors are sometimes attached to the needles of tangent galvanometers they are much more frequently employed in instruments where the wire is wound very close to the needles in order to still further increase their sensibility. One of the commonest forms is shown in Fig. 13, and consists of a circular coil of wire with a magnet and mirror *m* suspended in the middle of it. A large curved magnet supported above the coil serves to direct the suspended magnet, so that the spot of light is reflected to the required position on the scale.

Reflecting instruments are sometimes made astatic by attaching two magnets together as above described, and placing them so that one is inside and the other outside the coil, as in Fig. 8, or that each is within a separate coil, as in Fig. 9. The latter arrangement applied to a sensitive reflecting instrument is shown in Fig. 14. Each of the two coils is made in two parts, placed a small distance apart, so as to allow the wire to which the two magnets are attached to pass freely between them.

Another kind of instrument in common use is the differential galvanometer. The bobbins of such instruments are

preferably wound with two insulated wires side by side, instead of with only one wire. When the two coils thus formed are placed in separate circuits and so connected up that the currents pass in opposite directions, then any deflection of the needle must be due to the difference of the two currents; hence the

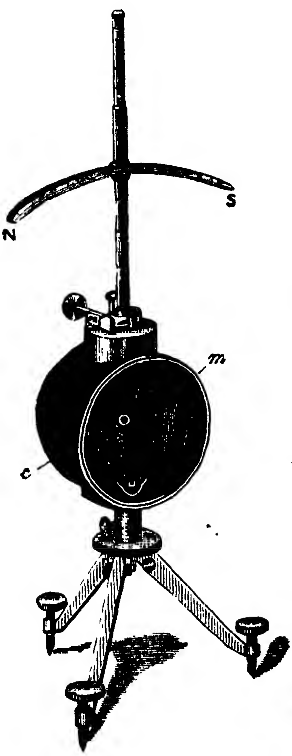


Fig. 13.—Tripod Reflecting Galvanometer.

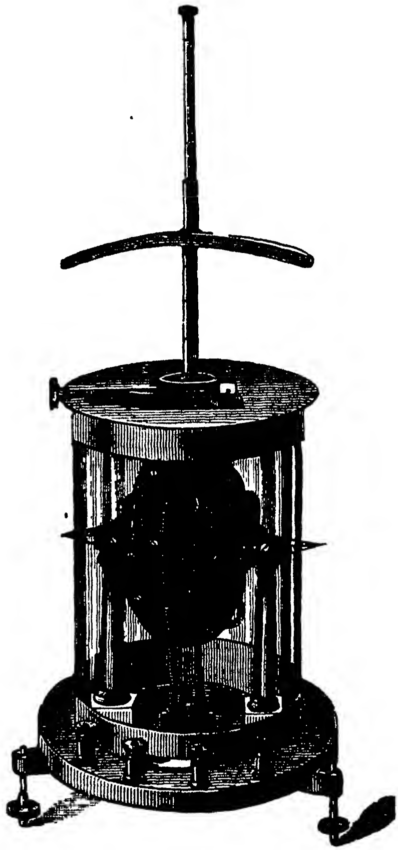


Fig. 14.—Astatic Reflecting Galvanometer with Two Pairs of Coils.

name "differential." It is most frequently used to indicate the equality of two currents.

So far we have dealt with galvanometers in which the coil of wire is stationary, and the presence of currents indicated by the

movement of a magnet. There is, however, another class in which the magnet is fixed and the coil moves, which has of late years come into more frequent use. Fig. 15 shows one form of such an instrument. The coil C is suspended by wires, *w w'*, between the poles of a powerful horse-shoe magnet, M M, and surrounds an iron core, K. When a current is sent in at the terminal T_1, it passes up the rod R, down the wire *w*, thence round the coil C, and to the terminal T_2 by way of the wire *w w'* and spring S. This current tends to make the coil turn round, and the motion is observed by means of a ray of light reflected from the mirror *m* as in ordinary reflecting instruments. When the current is

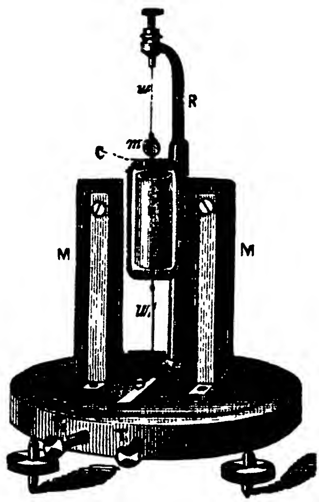


Fig. 15.—Galvanometer with Suspended Coil.

stopped the torsion of the wires *w'* bring the coil back to its initial position. This type of galvanometer, although fairly sensitive, is not much affected by bringing magnets near it, and hence it can be used near dynamo machines and in other places where the ordinary kind of galvanometer would be quite unsuitable.

In virtue of Ohm's Law (*see* Primer No. 3) galvanometers of both classes may be used to measure differences of potential or electric pressure as well as currents; for according to that law the current passing between two points of a circuit is equal to the difference of potential between the two points, divided by the

resistance between them. This is the same thing as saying that the difference of potential between two points is equal to the current passing multiplied by the resistance between them; and if the resistance be constant, then the difference of potential is proportional to the current: hence a measure of current may also be a measure of potential difference. It is on this principle that most voltmeters so common in electric light installations are made.

Some galvanometers, whose indications are not much affected by the presence of magnets, can be calibrated and provided with scales which show the current in amperes directly. Such instruments are called amperemeters or ammeters, and are more fully described, together with voltmeters, in Primer No. 12.

The following books may be recommended to those wishing to obtain further information on this subject:—

"Practical Electricity." By W. E. Ayrton.

"Practical Notes for Electrical Students." Vol. I. By A. E. Kennelly and H. D. Wilkinson.

"Elementary Lessons in Electricity and Magnetism." By Silvanus P. Thompson.

"Handbook of Electrical Testing." By H. R. Kempe.

ELECTRICAL MEASURING INSTRUMENTS.

Although the title of this Primer is somewhat comprehensive, its scope will be limited to instruments in ordinary use in electric light and power installations, and will only include ammeters, voltmeters, ohmmeters, and wattmeters.*

Such instruments consist of fixed and movable parts, and the position of the pointer which indicates the amperes, volts, ohms, or watts, depends on two forces, one tending to keep the pointer at zero, and the other tending to move it away from zero; the former we shall call the controlling force, and the latter the deflecting force. It is in the various ways of producing and disposing these forces that the differences in various instruments consists.

Ammeters.

Ammeters are instruments for measuring currents in amperes,* and the action of nearly all the various types depends on the magnetic property of electric currents. For this reason they may be called electro-magnetic instruments.

In all electro-magnetic instruments the deflecting force is produced by the passage of the current to be measured, whilst the control may be effected by permanent or electro-magnets, springs, weights, or tension of wires, &c. To produce the deflecting force the current in some cases acts directly on the movable system, as in Fig. 1; whilst in others it temporarily magnetises iron, and the deflecting force is mainly due to the attraction or repulsion between the parts so magnetised.

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* For definition of ampere, volt, ohm, and watt, *see* Primer No. 10, on "Electrical Units."

An instrument with permanent magnet control is shown in Figs. 1 and 2. Here the needle N, to which the pointer P is attached, is deflected by the current passing through the coil C,

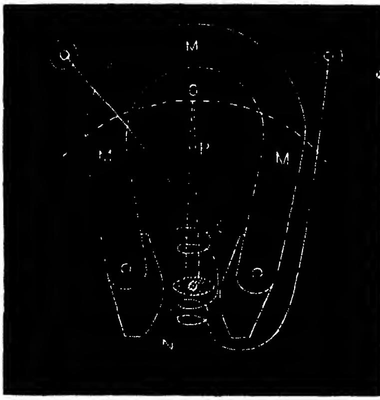


Fig. 1.

and restrained by the magnet M, which tends to keep it in the position shown.

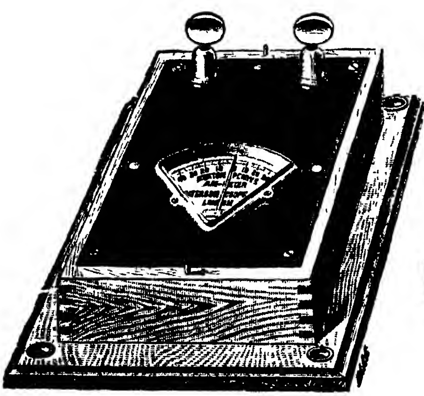


Fig. 2.

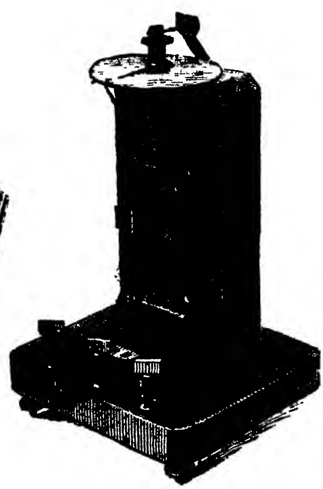


Fig. 3.

Siemens' electro-dynamometer, shown in Fig. 3, is an example of spring control. It consists essentially of two coils joined in series, and placed at right angles to each other. One of them is fixed and the other suspended. The current is led into and out of

the latter by mercury cups. When a current passes through the coils the movable one tends to place itself parallel to the fixed one, but it is brought back to its zero position by turning the milled head and pointer connected with the spring. The amount of turning necessary to do this is a measure of the current.

A second example is illustrated in Fig. 4, which shows Ayrton and Perry's Magnifying Spring Ammeter. Here an iron tube, T, whose top end carries the pointer, is attached by a collar, C,

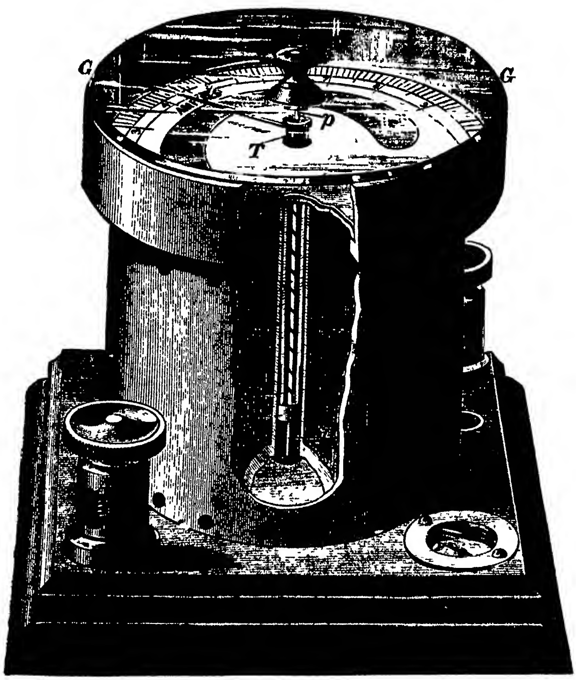


FIG. 4.

to a "magnifying spring," S, the upper end of which is fixed to the head H. When a current is passed round the coil of wire wound in the space W, the tube is pulled lower down into the solenoid by the magnetic action of the current. This stretches the spring, and causes it to untwist, and so turns the tube T and pointer p.

Another spring instrument is shown in Fig. 5. The spring, which in this ammeter is very strong, tends to hold a soft iron

needle nearly at right angles to the line joining the poles of an electro-magnet, energised by the current, whilst the magnet tends to place the needle parallel with this line.

Fig. 5.

The force of springs, or so-called permanent magnets, is not absolutely the same at all times and temperatures, hence of

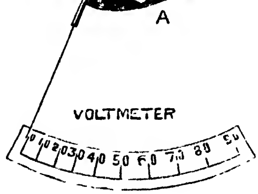


Fig. 6.

recent years there has been a growing tendency towards the use of weights or gravity as the controlling forces in ammeters and

voltmeters. Instruments of this kind are illustrated in Figs. 6, 7, and 8.

In the instrument shown in Fig. 6, which is made by the Société des Téléphones de Zurich, the needle is attached to a sort of horse-shoe shaped sheet of soft iron, A, pierced at intervals

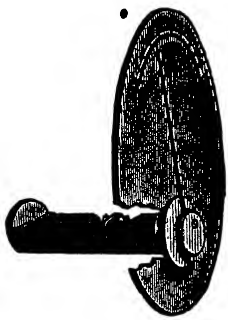


Fig. 7.

Fig. 8.

with holes. The stronger the current, the further is the horn drawn into the coil, whilst the weight of the sheet and pointer opposes this attraction.

The interior of Evershed's gravity ammeter is shown in Fig. 7, and the external appearance resembles Fig. 8. The slabs

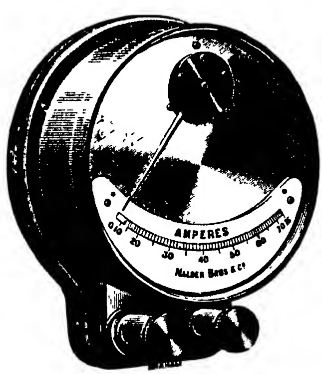


Fig. 9.

of iron (shown dark in the figure), and the iron bar carried by the staff, are rendered magnetic by the passage of a current in a coil surrounding them: the bar is thus attracted towards the slabs, and this attraction is balanced by the small weight, which tends to keep the pointer at zero.

In Nalder and Soames' instruments, Fig. 9, a bundle of iron wires forming the needle is repelled by a fixed wire placed within a coil, and both being made magnetic by the current to be measured. A small counterweight brings the needle to zero when no current is passing.

Voltmeters.

Voltmeters are intended to indicate electric pressure in volts, just as a pressure gauge shows the pressure of steam in a boiler in pounds per square inch. Their actions may be based either on the magnetic effects or the heating effects of electric currents,

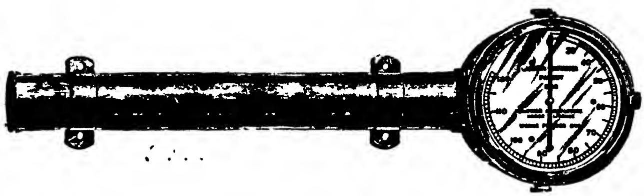


FIG. 10.

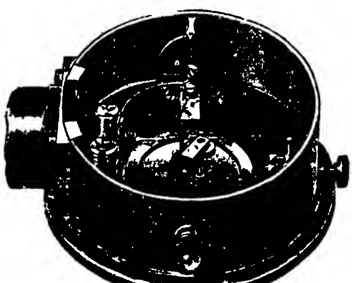


FIG. 11.

or on the attraction or repulsion between electrified bodies. Those included in the first category, viz., electro-magnetic instruments, measure in reality the currents passing through them, but if their resistance be constant, then by Ohm's Law (*see* Primer No. 3), the electric pressures between their terminals are proportional to the currents passing, and hence a measure of the current is also a measure of the pressure. For example, suppose the pointer of an instrument whose resistance is 100 ohms is deflected to a certain point on its scale by a current of $\frac{1}{10}$ of an ampere passed through the coil, the volts between the

terminals would by Ohm's Law, $V = CR$ (*see* Primer No. 3), be $\frac{1}{10} \times 100$, *i.e.*, 10, and if this point on the scale be marked 10, the instrument will read directly in volts, and hence be a voltmeter.

Electro-magnetic voltmeters differ from ammeters of the same type only in the fact that they are usually wound with long lengths of fine wire instead of short lengths of thick. They therefore need not be further described, for any of the forms above

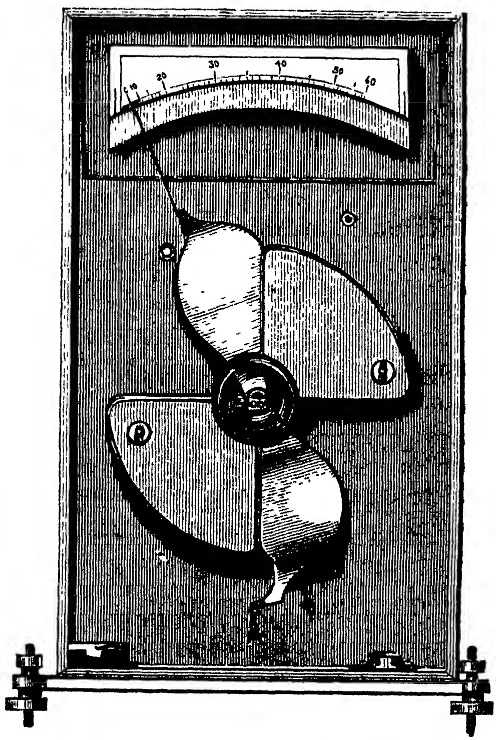


Fig. 12.

referred to can be wound as voltmeters; indeed, Fig. 8 represents one of Evershed's instruments graduated as a voltmeter. It should, however, be pointed out that if the coil of a voltmeter changes in temperature, its resistance is altered, and it will, therefore, require a different pressure to send the same current through it. Hence its accuracy as a voltmeter is affected, whilst as an ammeter it remains practically unchanged.

We will now pass on to the "Cardew" or "hot-wire" type, which depend on the extension of wires caused by the heat generated on passing electric currents through them. In the actual instrument shown in Figs. 10 and 11, the wire is enclosed in a long tube, and its extension is magnified by wheel-work. The wire used is very fine, so that it changes its temperature rapidly when the pressure between its ends varies, and its length is about four times that of the tube. A spiral spring keeps the wire taut, and as the latter extends the contraction of the spring causes the wheelwork to turn, and thereby moves the pointer.

The electrostatic type is specially suitable for measuring high alternating pressures, say 400 volts or more. Fig. 12 shows one form. Its action depends on the attraction between adjacent bodies between which a difference of electric pressure exists. The controlling force is gravity, and the vane carrying the pointer moves further in between two fixed quadrant-shaped pieces as the difference of electric pressure between the fixed and movable parts increases. Instruments of the electrostatic type can now be obtained reading as low as 20 volts.

Alternate-Current Ammeters and Voltmeters.

Some of the instruments above described are not suitable for measuring alternating currents (*see* Primer No. 16), or pressure, but those shown in Figs. 8, 10 and 12 may be used for this purpose. Mr. Evershed and Messrs. Nalder Bros. & Co. have, however, devised modifications of their instruments so as to adapt them for alternate current work.

Ohmmeters and Wattmeters.

Ohmmeters indicate the ratio of the pressure between the ends of a conductor to the current passing through that conductor, whilst wattmeters show the product of these two quantities, for the ratio *volts* ÷ *amperes* gives the resistance in ohms, and the product *volts* × *amperes*, the power spent in the circuit in watts. The principle of the ohmmeter is illustrated in Fig. 13, and the external appearance of one devised by Mr. Evershed in Fig. 14. In Fig. 13 x is the resistance to be measured. If this be very large then little or no current passes through the coil B, and that through the coils A A keeps the magnet N and pointer P in the position shown. If x be decreased, the current through B is increased, and P moves over the scale S to such a position that the needle is an equilibrium under the force exerted by the

coils A and B. The reading on the scale should then represent the resistance of x in ohms.

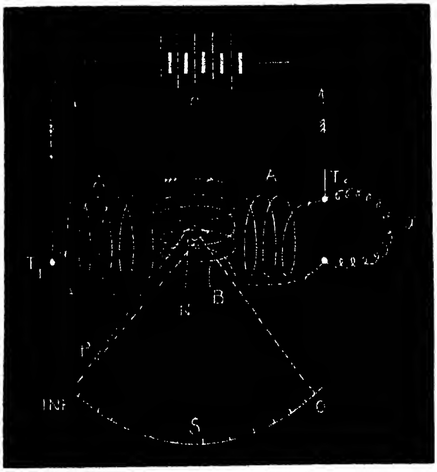


FIG. 13.

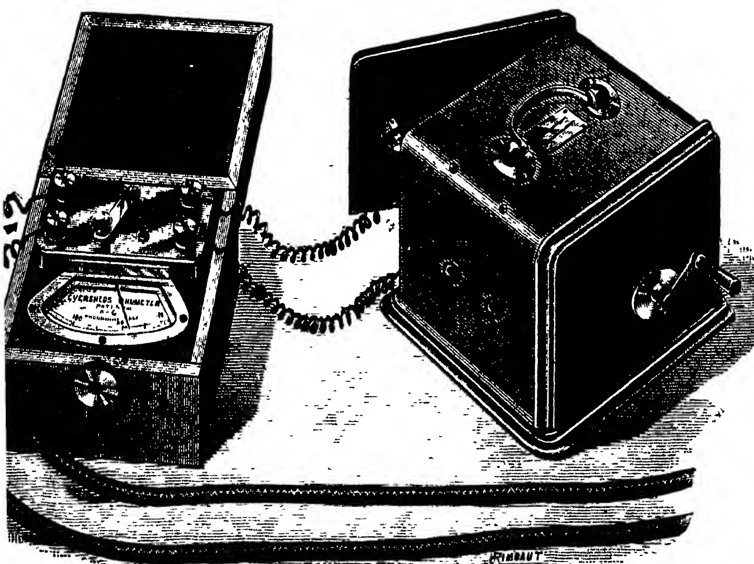


FIG. 14.

The same diagram (viz., Fig. 13) will serve also to illustrate the principle of the wattmeter, if the magnetic needle N be

supposed removed, and the coil B suspended. The force tending to turn B is proportional to the current in A multiplied by the current in B, and as the former varies as the pressure between T_1 and T_2, this force will measure the watts spent in the circuit T_1, B, x, T_2. The ordinary form of wattmeter is similar to Fig. 3, with the exception that one coil is of thick wire and the other of thin, and instead of being joined in series they are insulated from each other.

The following books may be recommended to those wishing to obtain further information on this subject :—

"Electrical Engineering." By Slingo and Brooker.

"Practical Electrical Measurement." By J. Swinburne.

"Practical Electricity." By W. E. Ayrton.

THE WHEATSTONE BRIDGE.

In order to understand the principle of the Wheatstone Bridge—which takes its name from Prof. Wheatstone, the inventor of many telegraph instruments—it is necessary to grasp the simple fact that whenever two points, between which there exists a

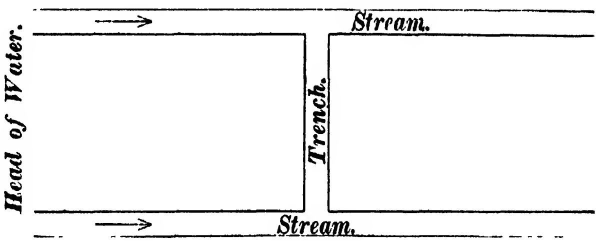


Fig. 1.

difference of electric pressure or potential, are joined together by a conductor, there will be a flow of electricity from the point of high pressure to that of low pressure. Electricity traversing a

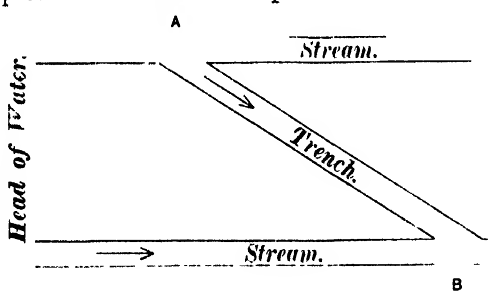
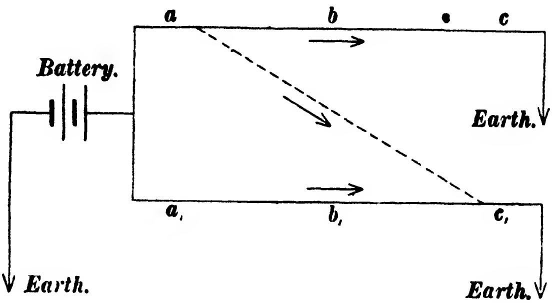


Fig. 2.

wire may be likened to a stream of water flowing down a hill. If there are two streams flowing on two paths, both having the same head flow and discharge, and if we suppose a trench to be cut straight across (as in Fig. 1) from one to the other, no water

would flow through the trench, because the facility for discharge would be the same in both cases. But if a trench were cut as in Fig. 2, water would flow from A to B, because the facility for discharge would be different at these points. So it is with electricity. If two exactly similar wires are joined to a battery



as in Fig. 3, the potential at equal distances a, a_1, b, b_1, c, c_1; from the + pole will be the same, and no current will flow from a to a_1, etc., there being no difference of potential. This can be ascertained by joining a galvanometer between any two points, and noting the absence of deflection. But if the galvanometer

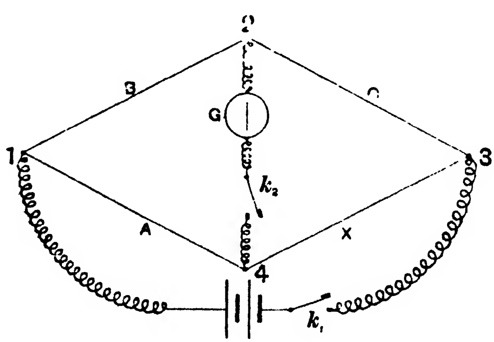


Fig. 4.

is joined up between a and c_1 it will deflect, because a current will flow from a, the point of high, to c_1, the point of low potential.

It can now be explained how this principle is applied in the Wheatstone Bridge to find the resistance of a wire.

In Fig. 4 we have a diagrammatic sketch of a Wheatstone Bridge. A and B are two known resistances, and C is an

adjustable resistance, also known. The branch X is the unknown resistance. A galvanometer, G, is connected as shown between the points 2 and 4, and a battery, P, between the points 1 and 3. Everything being ready the key k_1 is first pressed and then the key k_2. If a deflection is observed on the galvanometer the resistance C is altered until there is *no* deflection on pressing the galvanometer key. This shows that the potentials at 2 and 4 are equal. Now by Ohm's Law if i is the current flowing through B and C, and i_1 the current flowing through A and X, then the fall of potential along B + C equals $i \times (B + C)$, and similarly the fall of potential along A + X equals $i_1 \times (A + X)$. Also the fall of

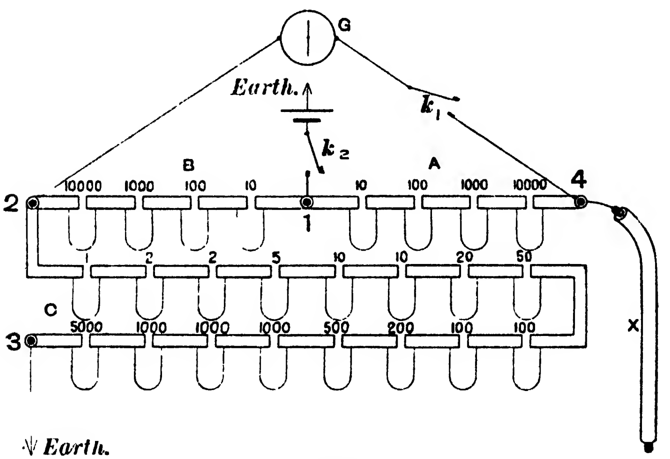


Fig. 5.

potential along A and B equal respectively $i_1 \times (A)$ and $i \times (B)$. But since the potential at 2 equals the potential at 4, and the total fall of potential from 1 to 3 along *either* path is the same, we have

$$\frac{i \times B}{i \times (B + C)} = \frac{i_1 \times A}{i_1\,(A + X)},$$

or

$$B \qquad A$$

or

hence

$$X = \frac{A}{B} \times C.$$

Fig. 5 shows a working plan of a Bridge. It will be seen that it corresponds with Fig 4, except in form.

If a cable is broken, and it is required to know how far away the break is, the following is the process to be taken: The two arms, A B (Fig. 5), of the bridge are joined to the battery by means of a key, so as to apply the current or to shut it off. The galvanometer is joined to the end of the arms, where also are joined the standard coils, C, on one side and the cable, X, on the other. The resistance of the arm C is then varied by putting plugs in and out of the holes marked 1, 2, 2, 5, 10, etc. When a plug is *in*, the resistance coil underneath is excluded from the circuit, and *vice versâ*. After several attempts at manipulating the plugs, it is found that, whether the current is applied or not, the galvanometer needle does not move after the cable has been charged. The total resistance X to where the cable is broken is then found

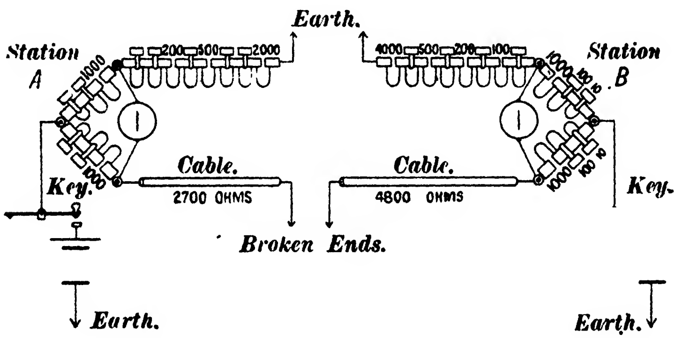


Fig. 6.

by the formula given on page 3. As each mile of cable has a known resistance, the total resistance must be divided by the resistance per mile, and this will give the distance in miles. If both stations can test it will be possible to compare the two results, which, if added together, will give the total resistance of the whole cable.

The following example and Fig. 6 will further explain this: A cable 1,500 miles long has a resistance per mile of 5 ohms, and a total of 7,500 ohms; it becomes broken at an unknown point. By applying the Bridge test at station A the galvanometer can be made to indicate that there is no difference of potential at its terminals when 2,700 ohms are unplugged, this would show that the cable is broken $\frac{2,700}{5} = 540$ miles from A. On testing at station B it is found that there is no difference of potential at

the galvanometer terminals when 4,800 ohms are unplugged, showing that the cable is broken $\frac{4,800}{5} = 960$ miles from B, 540 and $960 = 1,500$ miles altogether. It is possible, but not often, that results so accurate can be obtained, and these are the most favourable conditions under which a break could be tested.

[This subject will be found to be treated pretty thoroughly in the "Handbook of Electrical Testing." By H. R. Kempe.]

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320 PAGES. 155 ILLUSTRATIONS.

Practical Notes for Electrical Students.

VOL. I.—LAWS, UNITS, AND SIMPLE MEASURING INSTRUMENTS.

BY A. E. KENNELLY AND H. D. WILKINSON, M.I.E.E.

CHIEFLY designed for those who are but slightly grounded in electrical matters, and with this view the authors have endeavoured to render their language as simple as possible, and to exclude mathematical expressions.

ELECTROMETERS.

Bodies which are charged to different potentials are found to exert force upon each other, although in general the difference of potential must be large for the attraction or repulsion to be perceptible. An instrument which *indicates* differences of electrical pressure or potential by means of the mechanical forces which are exerted between electrically charged bodies is called an electroscope, and if by its indications actual measurements can be made, it is called an electrometer. Nearly every instrument which is used in practice for the measurement of volts is a form of high resistance galvanometer, and consequently acts by the passage of a current. An electrometer, however, acts without any current passing.

The electrical forces brought into action in these instruments are very minute, as the following example will show:—If two circular discs, each one foot in diameter, are placed with their planes horizontal, and so that one is half an inch vertically above the other, and if these plates differ in potential by 10,000 volts the electrical attraction between them will slightly exceed half an ounce. The force exerted is proportional to the area of the plates, inversely proportional to the square of their distance apart, and varies directly as the square of their difference of potential. This law is strictly true if the plates are parallel, and large compared with their distance apart. In the above example, if the plates had been one inch apart, the force of attraction would only have been one quarter as great, and if the voltage, instead of being 10,000, had been 100, a common voltage used in electric lighting, the force would have been reduced in the ratio of $10{,}000^2$ to 100^2, *i.e.*, it would only have been one ten-thousandth part of half an ounce, and thus quite imperceptible.

When high potentials have to be dealt with it is, however, quite possible to measure them by charging two such plates to the

voltage required, and making the upper plate one of the pans of a delicate balance. The electrical attraction between the plates can be weighed and the potential difference deduced. An instrument of this kind is called an absolute electrometer, and the one devised by Sir William Thomson is more widely known than any other, although it has not been much used. In this apparatus the attraction between the plates is balanced

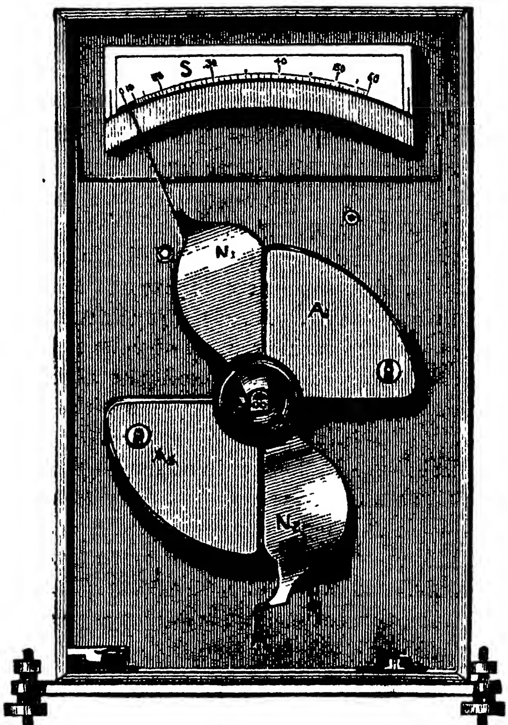


FIG. 1.

by stretching a spring which supports the upper plate, the force corresponding with this stretch being found from previous experiments. With this instrument it is possible to measure the potential of a body when charged with very small *quantities* of electricity indeed, but unless its potential exceeds 300 or 400 volts the measurement cannot be made satisfactorily.

Another form of electrometer is shown in Fig. 1. It is known as the electrostatic voltmeter of Sir William Thomson, and is

intended for practical use in high potential systems of electric distribution. The two metal quadrants A_1, A_2, are fixed, and are connected with each other and with one terminal of the instrument. The needle N_1, N_2 is movable about an axis perpendicular to its own plane and that of the quadrants, and is connected with the other terminal. When the terminals are joined to wires at different potentials the upper portion of the needle N_1 is attracted to the right by the quadrant A_1, while the lower portion N_2 is pulled to the left by A_2. The needle thus turns, and the pointer attached to its upper portion moves over the scale S to a mark corresponding with the potential.

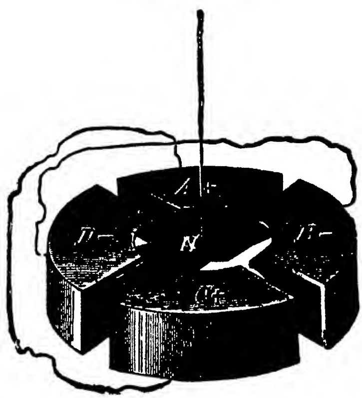


FIG. 2.

This instrument is, however, unsensitive for small potential differences. In order to make an electrometer sensitive to small voltages it is necessary to resort to a device which is exemplified in Sir W. Thomson's quadrant electrometer. The principle of this can be understood by referring to Fig. 2. A, B, C, and D are four quadrants, somewhat similar in shape to those formed by cutting a pill box into four equal portions along two diametral planes. Opposite quadrants are metallically connected, as indicated by the wires in the figure. The needle N is suspended so as to be free to turn within the quadrants. If the potential of N differs from that of the quadrants the needle will tend to turn with a force depending on the voltage V between the two pairs of quadrants, and also on the potential of the needle. By arranging so that the needle is always charged to a very high potential it is found that a very

small voltage V between the quadrants is sufficient to deflect the needle. So much is this the case that, when the apparatus is made as sensitive as possible, and a mirror is attached to the needle, so as to reflect and focus a beam of light on to a fixed scale, it is possible to make the index move more than a foot by causing the potentials of the quadrants to differ by one volt. A difference of 100th of a volt can thus easily be detected.

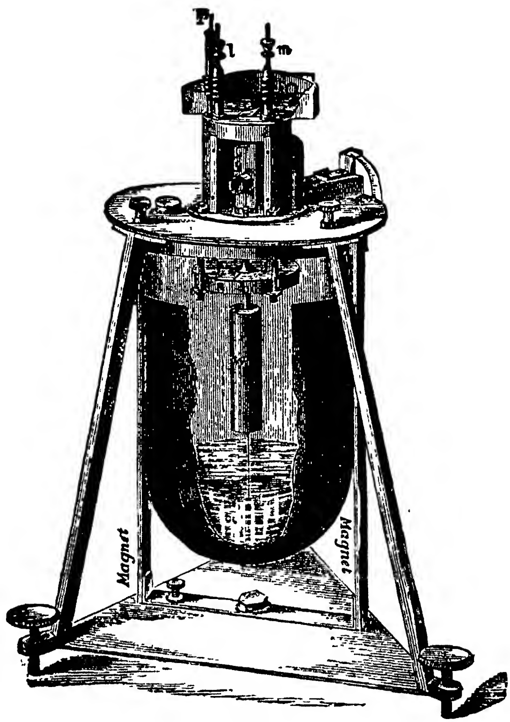


Fig. 3.

One form of this instrument is shown in Fig. 3. The front of the instrument is shown cut away for purposes of illustration. The quadrants are metallically connected with the terminals l and m, and are indicated by the letters a and b. The needle is, for lightness, made of very thin aluminium. It cannot be seen in the figure, as it is enclosed within the quadrants. It is supported by a wire, to which a mirror t is attached, and is connected with the acid at the bottom of the jar by a platinum wire, which is

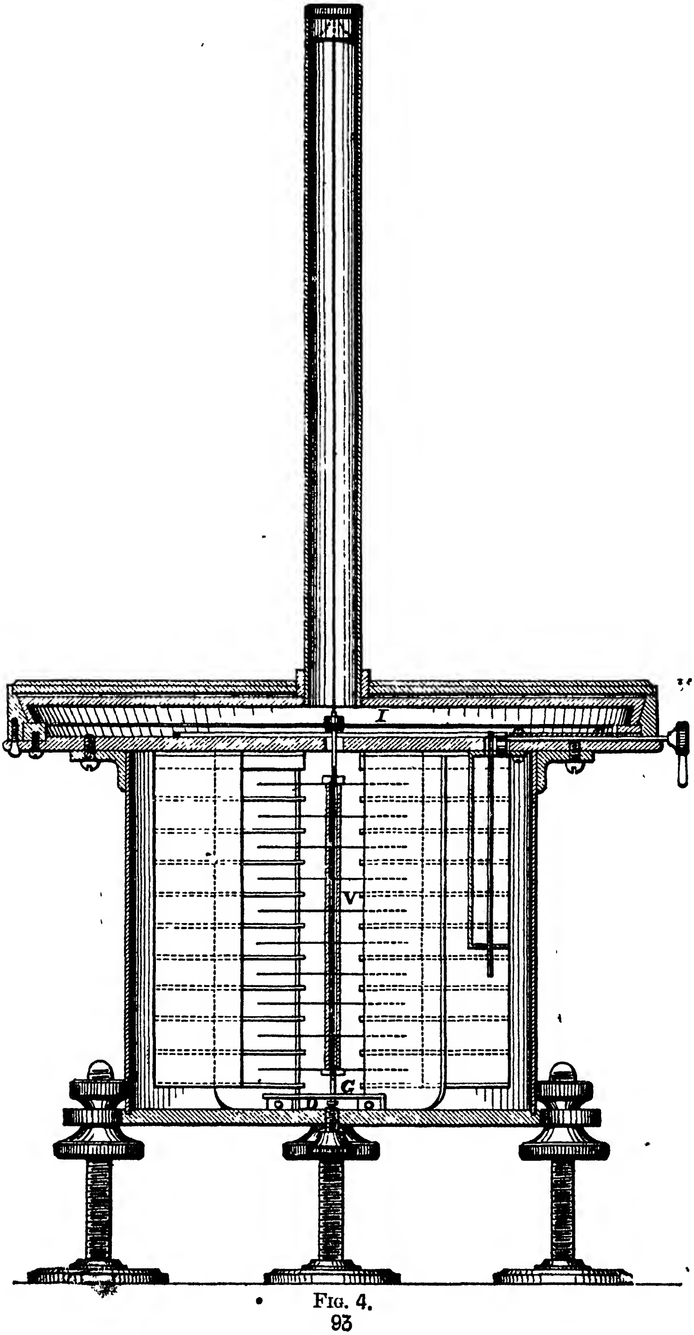


Fig. 4.

enclosed within the brass tube W. The terminal p is also connected, by a fine platinum wire, with the acid at the bottom of the vessel, and is called the needle terminal. The vessel itself is lined with tinfoil, so that it is a Leyden jar, capable of holding a charge. It is always kept charged to a high potential in order to make the instrument sensitive. The wire dipping into the acid is generally provided with a cross-piece, whose motion through the liquid is resisted by friction. This device saves time in the use of the instrument, since it prevents the

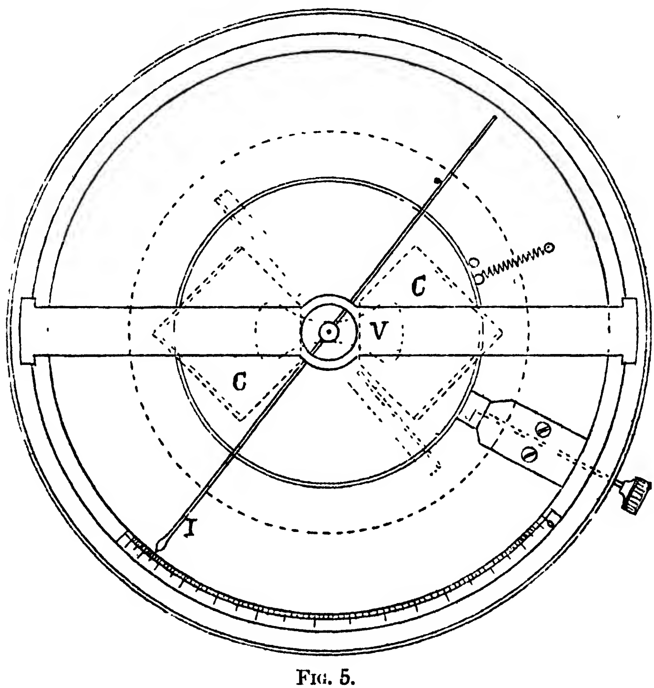


FIG. 5.

needle oscillating backwards and forwards before taking up its final position.

The quadrant electrometer, of which many modifications exist, is very well adapted to physical researches, and for the relative measurement of small potentials. It is, however, not suitable as a permanent measurer of volts, because its sensibility depends upon the charge of the needle, and unless this can be kept constant, its indications for the same potential difference will naturally vary. The impossibility of keeping the

potential of the needle constant is one reason why the quadrant electrometer is not used as a voltmeter. An electrostatic voltmeter, sensitive enough to read 20 or 30 volts, is, however, very much wanted; and Sir W. Thomson has, during the last two years, turned his attention to the subject. His efforts have resulted in the production of the multicellular voltmeter illustrated in Figs. 4, 5, and 6. Its principle is very simple, and it may be described as a combination of a number of instruments, such as that shown in Fig. 1, placed so that the

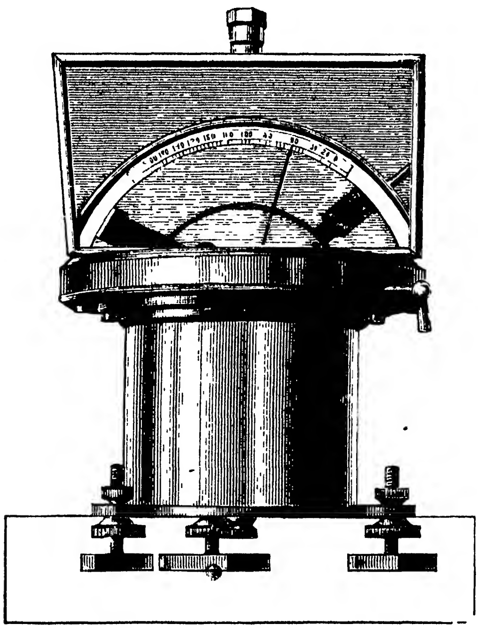


FIG. 6.

needles are all on one spindle, and so that all the quadrants are connected with each other. The instrument is shown in section in Fig. 4, and in plan in Fig. 5. The needle V consists of a number of vanes shaped like a figure 8, as in the quadrant electrometer, and placed parallel to one another on a spindle, with distance pieces between them. At the top of the spindle an aluminium index I is attached, and the whole is suspended by a fine platinum wire. The shape of the quadrant cells is indicated in Fig. 5. In order to use the voltmeter as an inspectional

instrument, capable of being read in an engine-room, a mirror is supported over the dial, so as to make an angle of 45° with the vertical. The instrument, with the mirror in position, is shown in Fig. 6.

Until the last few years electrometers have been used chiefly in physical laboratories. The voltages measured have generally been small, and, in order to make the instruments sufficiently sensitive for the measurement of very minute electrical forces, the moving parts have had to be extremely delicate. This has caused the instrument to be troublesome to use, as it is influenced by all sorts of disturbing forces which less sensitive instruments are quite incapable of responding to. There is, however, great need of an electrostatic voltmeter of a more practical type, capable of standing somewhat rough usage, reliable in its action, and such as not to need skill on the part of the observer. An electrometer has two very great advantages over all electro-magnetic instruments. It does not take any current, or absorb any power in producing its indications, and is one of the very few instruments which, when used for alternate current measurement, works as easily and as accurately as with direct ones. Its indications are, in fact, independent of the manner or frequency of the current variations. For these reasons the improvement of electrometers is a subject which deserves, and which is likely to receive, much attention.

THE INDUCTION COIL.

We have seen in the Primer No. 8, on "Lines of Force," that any wire conveying an electric current is surrounded by lines of force, and that when the current begins to flow a magnetic field springs into existence, to disappear immediately the current ceases. If, on the other hand, we put some lines of force round a wire—which we can do by bringing it into a magnetic field—we shall find that there is produced in that wire a tendency for an electric current to flow; in other words, an electro-motive force is induced in it, and if the ends of the wire are connected together a current will flow. But we shall also find that it is only while we are altering the number of lines of force which are looped round the wire that the electro-motive force exists; that is to say, while the wire is cutting lines of force, for since these lines are all closed curves we cannot loop them round a wire or perform the reverse operation unless they are cut by the wire.

If now we have two wires arranged side by side and send a current through one of them, lines of force, in the form of circles having the wire as centre, will be set up by that current in a manner somewhat analogous to the circular ripples produced by throwing a stone into a pond; and, if the wires are close together, most of these lines will be cut by the second wire. An electro-motive force will therefore be *impressed* on the second wire, and will be such as to tend to send a current in it in the opposite direction to the original or *primary* current. The impressed or induced electro-motive force is but momentary, lasting only while the lines of force are spreading themselves out round the wire, and ceasing as soon as the primary current has reached its steady value, which occurs almost immediately. If we stop the primary current the lines shrink up round the wire and disappear, again cutting the *secondary* wire, and impressing on it an electro-motive force, which in this case tends

to send a current in the same direction as the primary current. In other words, when we start a current in a circuit a reverse momentary secondary current will be induced in any other closed circuit placed near it; and when we stop the primary current another momentary current will be induced in the secondary circuit, which will be in the same direction as the primary current.

In order to obtain these induced currents we can arrange our two circuits in any way we please, provided the lines of force set up by the primary are cut by the secondary; but if we are using any considerable length of wire—and it is often necessary to use several miles—it is most convenient to wind both wires on the same reel or bobbin. The effect is also much increased by putting an iron core inside the coil, as a given current can set up many more lines of force in a piece of iron than it can in the air. A piece of apparatus so constructed is known as an *induction coil.* If we alternately start and stop a current in one circuit we shall set up momentary electro-motive forces in alternate directions in the other.

Let us now consider the magnitude of the secondary electromotive force. If we send a current through the primary circuit we set up a certain number of lines of force, depending upon the strength of the current, the number of turns of wire in the primary coil, and on the amount of iron and air which those lines have to traverse. Now, the impressed electro-motive force is proportional to the rate at which lines of force are cut by the secondary wire—that is, to the number of lines cut by the whole of the secondary wire per unit of time. But as each turn of the secondary coil cuts almost all the lines set up by the primary current, the secondary electro-motive force will, other things being equal, be proportional to the number of turns in the secondary circuit. If, therefore, we desire to produce a very high electro-motive force, and it is to this end that induction coils are usually employed, it is necessary to wind a very great number of turns of wire on the secondary coil. But it is also necessary that the secondary wire should be as near as possible to the primary, so that as many lines as possible may be cut by the secondary; from this it follows that if the secondary wire is very long it must also be very thin. It is, in fact, usual to wind it with wire only a few thousandths of an inch in diameter.

Induction coils are usually constructed in the following manner:—The iron core is made up of a number of thin wires insulated from each other, as such a bundle is found to be much

more susceptible to sudden changes of magnetism than would be a solid piece of iron. Round this, and suitably insulated from it, is wound the primary coil, consisting of a few layers of fairly thick copper wire, the length and thickness of the wire depending on the battery which it is proposed to use. Outside this again is

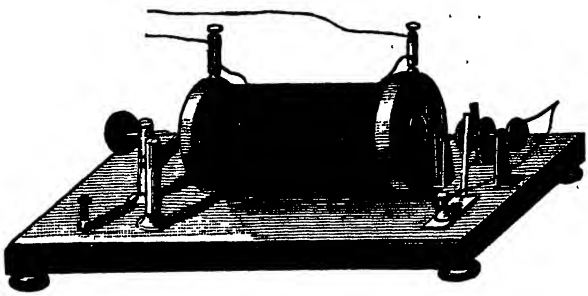


Fig. 1.

wound the secondary coil of many turns of very fine copper wire; but as the electro-motive force is usually very high, being often sufficient to give sparks from half an inch to several inches in length between the ends of the secondary wire, the greatest care

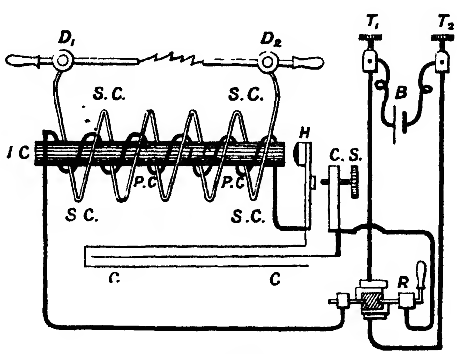


Fig. 2.

must be taken to insulate the secondary windings from those of the primary, and to insulate every turn of the secondary from every other turn. The secondary coil is often wound on an ebonite bobbin, into which the primary wire and core can be slipped, and a number of discs of ebonite are placed inside the bobbin,

parallel to its ends, so as to divide the secondary into a number of separate sections which are very well insulated from each other. The wire is of course silk-covered, and the whole coil is well soaked in melted paraffin wax, or other suitable insulating material.

The general appearance of an induction coil as ordinarily made is shown at Fig. 1. Fig. 2 is a diagram of the arrangement of the different parts; I.C. is the iron core, on which is wound the primary coil, P.C.; S.C. represents the secondary coil, its ends being connected to a spark discharging points, D_1 and D_2. It is necessary that the primary current should be stopped and started many times a minute; for this purpose a vibrating interrupter, similar in principle to an electric bell, is usually employed. Opposite one end of the core is a piece of soft iron, H, supported on a fairly stiff spring secured to the base of the instrument; a contact screw, C.S., normally touches this spring, the screw and spring where they touch being covered with platinum to reduce the wearing away due to the spark which occurs every time the circuit is broken. One end of the primary wire is connected to the spring, and one of the wires coming from the battery, B, is connected to the contact screw, the other battery wire going to the other end of the primary coil. (The arrangement shown at R is merely a commutator for reversing or stopping the primary current.) As soon as the circuit is completed the iron core, being magnetised, attracts the armature H, and draws the spring away from the screw, thus breaking the circuit and stopping the current. The core being now demagnetised, the spring draws back the armature and again completes the circuit. In this way the armature vibrates rapidly, producing correspondingly rapid interruptions in the primary current.

The efficiency of an induction coil is much increased by the addition of a *condenser*, made up of a number of pieces of tinfoil placed one above the other, and separated from each other by sheets of insulating material, such as paraffined paper. Alternate sheets are connected together, and one set is connected to the spring supporting the armature H, and the other to the screw C.S. The condenser is shown diagramatically at C.C. as if it consisted only of three sheets of tinfoil.

Induction coils have been largely used by physicists engaged in experimental researches on electrical discharges, and more recently for performing Hertz's experiments on electrical radiation; they have also received practical application in telephony.

If a microphone is connected to a long line wire having a relatively high resistance, a change of resistance in the microphonic contacts would produce but a small alteration in the strength of the current; the microphone is therefore usually connected to the primary wire of a small induction coil of low resistance, the secondary circuit of which is connected to the line wire. A change of resistance of the microphone produces a variation of the primary current, and currents are induced in the secondary which, owing to their greater electric pressure, are adapted for overcoming the resistance of the line wire.

Induction coils are also used in connection with the electric transmission of energy. When used in this way they are known as transformers, or converters, and are constructed in a somewhat different way to the induction coils we have been considering; in principle, however, they are identical. An induction coil as described above is ordinarily used to convert or transform a comparatively large current of low pressure into a much smaller current of high pressure. If now we reverse this process and supply the induction coil, or transformer, with a small intermittent high-pressure current we can have in the secondary (that is, the thick wire) circuit a much larger low-pressure current; such intermittent high-pressure currents are ordinarily produced by means of alternating-current dynamos. This arrangement is of advantage if we wish to transmit power electrically to a great distance, for even a small current at a pressure of one or two thousand volts represents a considerable amount of power, and the current being small it can be conveyed by small conductors. Such a high-pressure current is, however, unsuitable for electric lighting purposes; it is therefore converted into a larger current at fifty or a hundred volts pressure at the place where it is to be used by means of a transformer. The use of induction coils in this way is more fully considered in Primer No. 28, on "Alternate Current Transformers."

ALTERNATING CURRENTS.

Electrical currents may be (i.) steady; (ii.) varying or intermittent; or (iii.) alternating. Steady currents flow always in the same direction, and do not change in value. Such currents are produced by primary and secondary batteries, and by dynamos which are provided with commutators. If they are passed through coils of wire, the magnetic effect is constant. An intermittent current may be produced by frequently breaking the continuity of an electric circuit, and a varying current is caused by altering the resistance or electromotive force acting in the circuit. Although the magnitude of such currents does not remain constant, the direction in which they flow does not alter. When a current alters in direction from time to time it is called an alternating current, and with the currents of this kind used in practice the number of alternations per second is very large (100 to 200).

Alternating currents have, during the last few years, come into general use. Their properties are more complex than those of steady currents, and their behaviour much more difficult to predict. This arises from the fact that the magnetic effects are of far more importance than is the case with steady currents. With the latter the magnetic effect is constant, and has no reactive influence on the current when this is once established; but the lines of force produced by alternating currents are changing as rapidly as the current itself, and thus induce electromotive forces in neighbouring circuits, and even in adjacent parts of the same circuit. This inductive influence of alternating currents renders their action very different from that of ordinary unidirectional ones.

If a *slowly* varying, or alternating, current is passed through a glow lamp, the filament will be seen to vary in brightness

following the change of current strength. If, however, the alternations take place more rapidly than twenty per second, the eye cannot follow the variations quickly enough, and the lamp appears to burn quite steadily. The strength of the steady current which would make the lamp burn equally brightly, is said to be the strength of the alternating current. It is evident that this value is a mean of all the values of the current during the alternation, and that the maximum current is greater than this mean value in a ratio dependent on the way the current varies. The alternating currents used in commerce reverse about 200 times every second, so that lamps lit by them burn quite steadily, and, in fact, appear just as if they were lighted by the passage of an ordinary unidirectional current. The way in which alternating currents used in practice vary with the time is such that the *maximum* value of the current is 1·41 times the value of the steady current which would produce the same luminous effect in a glow lamp. Thus, if a glow lamp requires a steady current of ·6 ampere to make it give out a light of 16 candle-power, an alternating current of this mean value will at one part of its period be equal to $1{\cdot}41 \times {\cdot}6 = {\cdot}846$ ampere; and this current will be sometimes flowing in one direction and sometimes in the opposite, so that the change of current will be twice this amount, *i.e.*, 1·69 ampere, or nearly three times the nominal value of the current. The voltage absorbed by the lamp will, of course, be alternating too, so that if an average of 100 volts is necessary for the lamp, the voltage will at times rise to as much as 141 volts, and each terminal of the lamp will, during every period, vary in potential by as much as 282 volts. The insulation of wires intended for alternating currents must therefore be more carefully attended to than is necessary with steady currents, because the voltage to which the insulation is subjected is far in excess of the nominal, and because the stress is not a steady one, but is analogous to a vibration.

Instruments intended for the measurement of steady currents will not, as a rule, give correct indications when alternating currents are passed through them; nor can the electric pressure on alternating current circuits be measured by ordinary voltmeters. Special instruments have, in fact, to be used for alternating current work. In a circuit through which a steady current is flowing the substitution of one conductor for another makes no difference, provided the resistance is the same for both. With alternating currents this is not necessarily true. One of

the conductors may consist of a coil which the passage of a current converts into a magnet, and although this has no influence on the strength of a steady current, it may considerably influence the value of one which is alternating, because, owing to what is described as the self-induction or inductance of the coil, a back electromotive force is generated in it, whose strength is proportional to the rate at which the current is changing. This back electromotive force prevents the current rising to the value it would otherwise do in accordance with Ohm's Law, and its influence becomes more and more important as the number of reversals of current per second increases. It is thus possible for a coil, which, under a steady pressure of 10 volts, will pass a current of 1 ampere, to require over 100 volts alternating to produce the same current. In the former case the *resistance* is said to be 10 ohms, and in the latter 100 ohms is said to be the *impedance* of the coil. The impedance of any coil is dependent on its resistance, its inductance, and on rate of alternation of the current.

It must not be supposed that the resistance of a coil for alternating currents is any different from its resistance for steady currents, or that Ohm's Law is only true for the latter. In order to apply Ohm's Law, it is necessary to take account of all the electromotive forces in the circuit, whether these are due to external sources of current, such as dynamos or batteries, or to self-induced electromotive forces in part of the circuit. When these are all added together, the current is always obtained by dividing the algebraic sum by the resistance. It only happens, in the case of an inductive coil, that the simplest way of taking the induced potential into account is to use the law of impedance, which is merely an extension of Ohm's Law, and according to which the current is obtained from the voltage by dividing by a quantity called the impedance of the coil. The impedance is measured in ohms, and is equal to the resistance when the current alternations are very slow, but when the reversals are very rapid the former may be many times the latter.

A most important thing in dealing with alternating currents is the shape of the curve of alternation. To explain the meaning of this term let us suppose that the current in one direction through the conductor is at one moment equal to 10 amperes, and at the end of one second from that moment it is equal to 10 amperes in the opposite direction. Now let us take a horizontal straight

A B, as in Fig. 1, and divide it into ten equal parts, each

representing the tenth of a second, and erect a perpendicular, A D, at one end of the line to represent the 10 amperes of current in one direction (positive), and another perpendicular, B F, on the other side of the line to represent the negative current. Then, if the current decreased at the same rate all the way from +10 to −10 we should have at the end of the first tenth of a second + 8 amperes, at the end of the second tenth + 6, and so on, and the value of the current at any time during the whole second would be represented by drawing a straight line from D to F, and measuring its distance from the horizontal line A B at the time required. But in practice it is not necessary, or probable, that the current will vary at the same rate throughout an alternation in this way. In the most simple form of dynamo the resulting current decreases from its maximum points

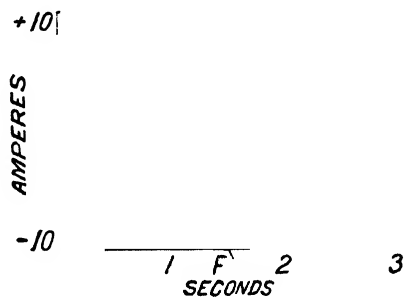


Fig. 1.

at first more slowly, and afterwards more rapidly, than is represented by the straight line D F. It is more nearly represented by the curved line C D E F G H I in this figure, which is part of a "sinusoid" or curve of sines.

The volts and amperes in alternating current circuits are all alternating with the same rapidity, but they do not necessarily rise and fall together so as to attain their highest value at *the same moment.* If there is much self-induction in the circuit, the current lags behind the potential, so that the volts rise to a maximum before the amperes. This effect is described as a difference of *phase*, and it is measured by the ratio of the time elapsing between the moments at which the maximum values of volts and amperes occur to the time of a complete period. Difference of phase is as important to consider with alternating currents

as amperes and volts, and produces very striking effects. Thus it is not always correct to measure the power supplied to an alternating current circuit by taking the product of volts and amperes, and it sometimes happens, in consequence of this difference in phase, that if a current divides into two portions, by means of branched conductors, the sum of the currents in the branches exceeds the current in the main circuit. Space, however, does not permit our entering a detailed explanation of these matters in this little Primer.

A somewhat advanced treatment of this subject is to be found in "The Alternate Current Transformer." Vol. I. By Dr. Fleming.

THE LEYDEN JAR.

The Leyden Jar consists in general of a glass bottle coated on its inner and outer surfaces with tin-foil. The metal coatings cover only the lower part of these surfaces, leaving a bare part near the mouth of the jar. In some instances the jar is fitted with a cork or wooden stopper through which a brass rod passes. One end of this rod touches the inner coating, the other terminates in a spherical knob (Fig. 1). The jar is named after

Fig. 1.

the city of Leyden, where it was first made. The honour of having discovered its action is claimed for more than one philosopher of the eighteenth century.

Considered as a means for scientific investigation, the Leyden jar has been and still is of great value. The behaviour of its discharge currents have assisted in the modern progress of electrical and optical theories; while its vivid flash is a great boon to the analytical chemist and the physicist, since it will effect rapid chemical changes or volatilise refractory substances. In engineering work, however, it has not found much employment, though a modification of the jar, known as the *condenser*,

is largely used in telegraphy. The action of the Leyden jar is to store *energy* by virtue of opposite electrical charges on the two sides of the glass. The names *positive* and *negative* are given to these opposite or complementary kinds of electrification. Between the two bodies thus oppositely charged there is a stress or force of attraction; and in the stressed medium energy is stored as long as the bodies are kept insulated from one another.

The greater the difference between the two electrifications the greater are the amount of energy stored and the intensity of the stress between them. If the outer coating of a Leyden jar is electrically connected to the earth by placing it on the floor or on an ordinary table (without a cloth), any positive charge communicated to the inner coating will *induce* the complementary negative electrification to appear on the outer coating. By increasing the charge on the inner coating greater stress is produced, more of the opposite charge is induced on the outside, and a greater amount of energy is stored. This can be continued until the glass is so strained that it cracks and allows a spark to pass across it.

The energy stored in a charged jar may remain in it for a considerable time without much loss, provided the atmosphere is dry and free from dust. But when the coatings are connected by a wire or metal rod the energy in the jar sets up an electric current in the connecting conductor, and this is maintained until the coatings have no difference of electrical condition. The discharge is usually very brief, the whole of the energy frequently being spent in a small fraction of a second. For the time, however, a vigorous action ensues; sufficient, in fact, to produce a vivid spark in a short gap in the discharging circuit. The heat developed by this spark will ignite gunpowder or volatilise gold; and the intensity of the discharge is such that an unpleasant shock is felt by the person who becomes a discharging conductor by touching both coatings at the same time. Much physical injury may be produced by such shocks, and discharges should never be taken by inexperienced people except from very small jars.

That a discharging Leyden jar actually produces an electric current may be shown by passing the discharge through an insulated wire wound in a coil round a piece of steel. The steel is magnetised. It is worthy of notice that the direction of magnetisation is often the opposite to that which would be expected from the arrangement of the positive and negative

charges in the circuit. The Leyden jar appears to send a current sometimes in one direction, sometimes in the other. In fact, it often develops a current which is rapidly varying in direction, an *oscillatory* or alternating current. To clearly understand how this can be the case we may refer to Fig. 2, which represents an hydraulic analogue, or model of a Leyden jar. Many electrical actions can be illustrated by mechanical and hydraulic models; and this particular one is due to Dr. Oliver Lodge, a somewhat similar model being described in his "Modern Views of Electricity and Magnetism."

A water-tight box is divided into two equal compartments, A and B, by means of a gutta-percha partition, G. The com-

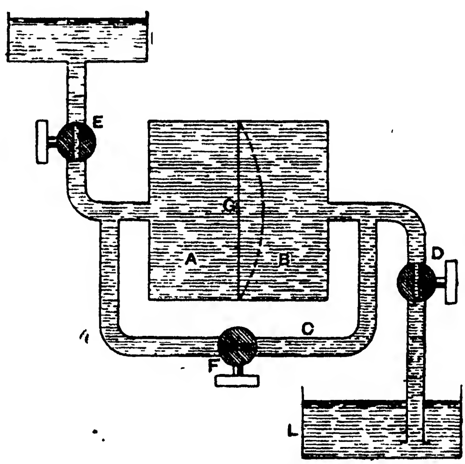


Fig. 2.

partment A is connected to a high-level water tank, H, by means of a pipe with a cock, E; and the compartment B is connected to a low-level tank, L, in a similar manner. A third pipe, C, connects the two compartments when the cock, F, is turned on. The whole system is filled with water—a practically incompressible fluid. If the cocks D and E are turned off, while F is turned on, the amounts of water in the two chambers will be equal, and the partition will not be strained. When F is turned off the compartments are insulated from one another, and if now the two cocks D and E are turned on, the difference in level between the tanks H and L will cause

a difference of pressure on the two sides of the gutta-percha. The partition, G, is thus bulged into the position shown by the dotted line, water entering the compartment A, and an equal amount leaving B. The compartment A may be said to be positively charged with water; the other compartment, since it has lost some water, may be said to be negatively charged. Energy is stored in the strained gutta-percha. This operation very closely resembles the charging of a Leyden jar when its metal coatings are connected to bodies at different electrical potentials or pressures. The compartments A and B represent respectively the positive and negative coatings, and the gutta-percha partition corresponds to the separating thickness of glass. The model will further illustrate a Leyden jar in its discharge. Let the cocks D and E be closed; the system remains charged as long as no communication exists between A and B. On opening F, however, such communication is established, and the elastic force of the strained gutta-percha causes a stream of water to pass from the positive to the negative compartment along the pipe C. The stored energy is expended in producing this water current. If the resistance offered by the pipe C is very great, the water may take some time to pass from A to B, a current lasting all this time. But if C is a short pipe of large bore, so that it offers very little resistance, there will be an impulsive rush of water through it; an energetic action of very transient duration. In this latter case, the gutta-percha partition in recoiling will spring past the flat position, and will bulge out a little on the other side. Too much water will be forced into B, and this, on returning, will constitute a reversed current in the connecting pipe. Thus it may happen that the gutta-percha partition oscillates to-and-fro for some time before coming to rest; maintaining all the while an oscillatory discharge in the pipe C. Under analogous conditions a Leyden jar will produce an impulsive rush discharge of an oscillatory nature, a transient alternating current existing in the connecting wire. The number of oscillations occurring in a second is often very large; indeed, it is possible to produce artificially as many as 30 million alternations per second.

Further explanation of the most recent views on this subject is to be found in

"Elementary Lessons in Electricity and Magnetism." By Silvanus P. Thompson.

"Modern Views of Electricity." By Dr. Oliver Lodge.

See also "Practical Electricity." By W. E. Ayrton.

"The Electrician" Primers.—**No. 18.**

INFLUENCE MACHINES.

When any conductor, such as a metal ball or plate, is brought near an electrically charged body, an action occurs in the intervening space which results in an electrification of the conductor. The electrical charge in the conductor is not accompanied by any variation in the charge on the other body; the electrification being, therefore, produced at no expense of the neighbouring charge. This phenomenon, formerly, and for a long time known by the name of *electrostatic induction*, is now also called *influence*. Its discovery was made in 1753, by John Canton, of Stroud.

The action of an electrical charge in thus influencing a conductor in its neighbourhood, may be explained as follows:—Whenever one body is electrically charged, another body somewhere in space must be charged with the complementary electrification. Between these two bodies there is a stress or force of attraction; so that every charged body is surrounded by a medium which is stressed or affected by the charge. If an unelectrified conductor is placed near an electrified body, and at the same time is connected to the body which has the opposite charge, a readjustment of the stress in the surrounding medium takes place, and some or all of the opposite charge will be transferred to this conductor. The amount of the opposite electrification which will thus be induced to appear on the conductor will depend on its proximity to the charged body; if it is very close, it may happen that, practically, the whole of the opposite charge is transferred to its surface. The earth may be regarded as a gigantic storehouse, from which the complement of any charge may be withdrawn; in other words, if any conductor under this electrical influence is connected to the earth, an opposite charge is induced to appear on its surface.

In 1776, Volta invented an instrument, called the *electrophorus*,

the action of which is identical with that of modern influence machines. This instrument consists of an electrified cake of resin, upon which rests a movable metal disc, attached to a handle of some insulating material. Owing to the slight irregularity of the surface of the resin, the metal touches it at only a few points; the greater part of their surfaces being separated by a thin film of air. The disc is, therefore, under the influence of the charge on the resin cake. On touching the disc with the finger, thereby connecting it with the earth, this influence causes an opposite electrification of the disc; so that, when the finger is removed, and the disc carried away by the insulating handle, it is in a condition of electrification nearly equal, but opposite in character, to that on the resin. This charge may be imparted to any other body; thus, for example, it may be sparked into a Leyden jar; and the operation may be repeated. In fact, the electrification of the disc may be repeatedly carried on, as long as the conditions of insulation allow of a charge remaining on the resin. Thus, an almost unlimited amount of electrification can be effected by the repeated influence of a very small charge.

Influence machines are contrivances for carrying on the successive influences of the charge in rapid succession. They are, in point of action, a species of electrophorus, in which the metal disc acts as a carrier of electric charges to a fixed conductor or collector; the necessary alternations of inductive influence and of discharge into the collector being effected in quick succession, by means of a rotary motion of the carrier disc. In many machines a large number of carriers are arranged in a circle on a revolving plate of glass or ebonite, rapidly following one another as they pass into and out of the influence of the charge, or as each pours its charge into the collector. This arrangement yields an enormous increase in power; and, when the revolving plate is moved at a high speed, develops an almost constant stream of charges from the discs to the collector.

In the influence machine, invented by Mr. Wimshurst in 1881, and shown in Fig. 1, there are two rotating glass plates, each with a circle of metal carriers. The plates are rotated in opposite directions by turning a single handle in the lower part of the machine. Each of the two sets of carriers are influenced by the charges on the other set; so that a carrier here acts both as influencing and as influenced body. The charges are communicated to the pair of collectors by means of two horizontal metal combs, which draw off the charges as the carriers pass in

front of them. The teeth of the combs do not touch, but come very close to the passing carrier. On turning the handle, the glass plates are set in rotation, and in a very short time the machine will have charged itself, and electric sparks will pass between the knobs at the top. If the machine is worked in a dark room a beautiful effect can be observed: the whole machine appears bathed in faint bluish light, and the discharge from the carriers to the comb is distinctly visible.

Very powerful machines of this type are obtained by combining a number of pairs of glass plates, each with a set of carriers. One of these, consisting of six pairs of plates, is shown in Fig. 2; the plates being contained within a glass case, and the collectors being connected to discharging knobs supported on

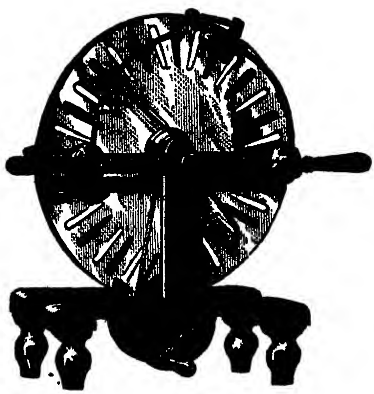


FIG. 1.

pillars at the top of the case. When the handle is turned very rapidly, sparks of considerably over a foot length can be produced. Fig. 3 represents some photographs of actual sparks of nearly fourteen inches length, obtained from one of these machines. If the knobs are separated beyond the sparking distance, a bluish brush discharge, accompanied by a hissing noise, is constantly produced, an effect that is more clearly seen in a darkened room. The brush discharge is shown in Fig. 4.

The great length of spark which influence machines produce is one of the best indications of their extremely high E.M.F. It can be shown that 1000 volts will not produce a spark of greater than $\frac{1}{200}$ inch length in dry air. From this it will be seen that

the E.M.F. of a machine which will develop sparks a foot long must be many hundred-thousands of volts.

It is a notable fact that the influence machine is a reversible

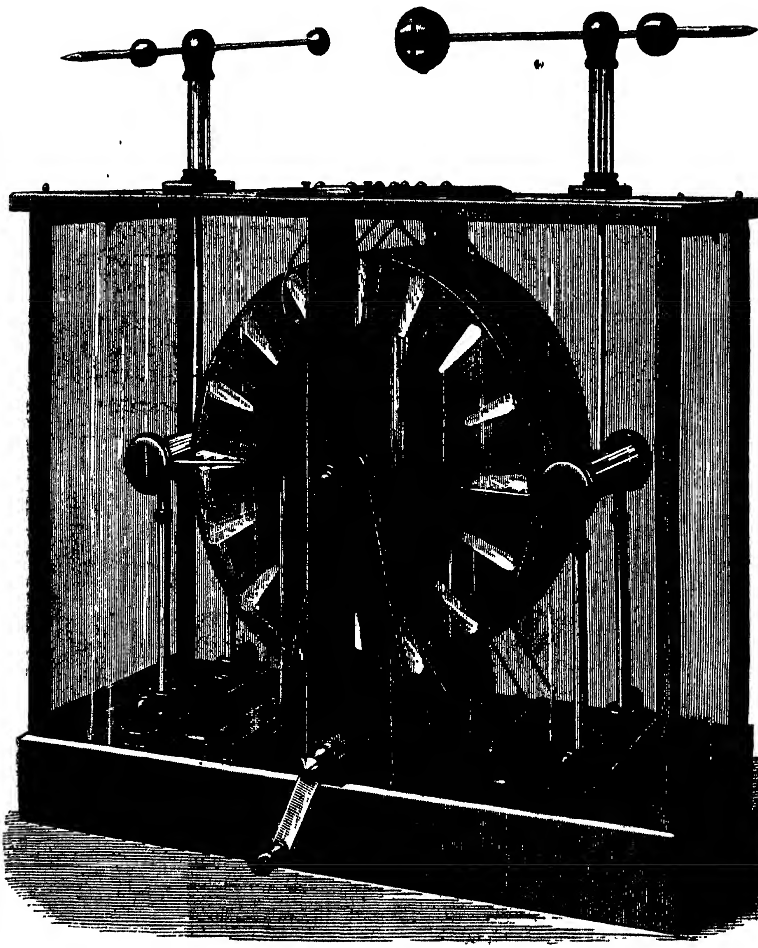


Fig. 2.

engine, in which respect it resembles a dynamo. Just as a dynamo may be made to drive another dynamo some distance away, the current developed by the former causing the latter to

run; so, an influence machine in motion, with its collectors connected by insulated wires to those of a similar machine, will drive the latter as a motor. The system is of scientific rather

Fig. 3.

than commercial interest, as, considered as a mode of transmitting power, it is very inefficient as well as inconvenient.

Besides the almost numberless applications of the influence

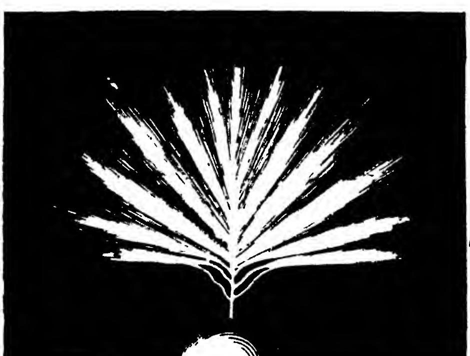


Fig. 4.

machine to physical and chemical research, such as in producing electric discharges in "vacuum tubes" or highly rarefied gases, there are two chief applications of it to commercial purposes.

It has been employed to light gas burners; a small influence machine contained within a small cylinder being actuated by the finger and producing a tiny spark at the end of a metal tube held over the gas jet. It has been employed on a very much larger scale to deposit smoke and lead fumes. When an electric discharge takes place in an atmosphere in which smoky fumes are suspended, a curious whirling motion is set up, and the particles of matter in suspension quickly aggregate into large flakes, which are deposited on the floor of the chamber containing the smoke. This behaviour of electrified smoke particles has been taken advantage of in lead works for the rapid deposition of large volumes of lead-fume, a powerful Wimshurst machine, driven by a gas engine, being used for the purpose.

The following books may be recommended to those wishing to obtain further information on this subject:—

"The Influence Machine." By Andrew Gray.

"Elementary Lessons in Electricity and Magnetism." By Silvanus P. Thompson.

"*The Electrician*" *Primers.*—**No. 19.**

LIGHTNING PROTECTORS.

Since the day on which Franklin drew electricity from a thunder-cloud by means of his kite, we have known that lightning and ordinary electric sparks differ merely in degree and not in kind. The immediate result of this experiment was to suggest means for preventing the destruction of buildings, &c., by lightning. Previous to this, one of the chief dangers in connection with any tall building was its liability to be struck by lightning, and either partially destroyed or set on fire: furthermore, vessels at sea were often damaged by being struck by lightning flashes, so that lightning was one of the seaman's greatest foes. To-day (thanks to Franklin's discovery) when a building or vessel is struck, there is but little damage done to either, if they be efficiently protected by a lightning conductor.

Before describing such a conductor, we will briefly consider what is the nature of a lightning flash, and what are the conditions under which it will occur. For a lightning flash to take place, we must have a cloud so highly charged with electricity that the electrical pressure between it and the earth may be sufficient to overcome the resistance of the air, and then a spark to the earth, or flash of lightning, will occur. The case is thus quite analogous to the familiar experiment of discharging a Leyden jar (*see* Primer No. 17), and the best analogy to a lightning flash is such a discharge. Now, such a discharge would not at all resemble a current sent by a battery: the latter would be always the same strength, while the current of a lightning flash would rise very quickly to a very high value, and then decrease very quickly to nothing. The phenomena in a case like this are very different from the ordinary ones. We first notice that although the quantity of electricity which passes to earth may not be very large, as it has to pass in a very minute fraction of time, the maximum current may be very large indeed.

in fact, thousands of amperes. In the second place, as was stated in Primer No. 16, on "Alternating Currents," the resistance which a metallic rod offers to a rapidly altering current will be many times the resistance it offers to an ordinary steady current.

A lightning conductor consists of one or more rods fixed to prominent parts of a building and connected by a metallic cable to earth. It is important to have a perfect metallic connection from top to bottom. The earth connection consists either of a plate of copper (3ft. or 4ft. square) immersed in damp ground or in water, or else of the water or gas mains, &c. In the case of a vessel, the conductors are fixed to the copper sheathing.

From theoretical and economic reasons, iron is the best metal to use, though it is customary in England to use copper. Many points must be attended to in setting up a conductor; and some of these we will now mention. In the first place it should be made of sufficient cross-section to avoid deflagration by a violent flash: this is the sole consideration which limits size. The earth-plate should be fixed in damp earth, and connected to all water or gas mains. It is better to have several rods on a building rather than one only, the whole being connected together, and to earth. In the case of factory chimneys (which, from their height, are peculiarly likely to be struck), it is best to fix one of the rods to a metal arch put over the top, so as to be in the current of hot air. The only way to completely protect any building is to encase it in a metallic cage, and this is certainly advisable in the case of powder magazines and such buildings.

We must now consider the protection of telegraph lines and cables from lightning. The protection of the latter is a point of very great importance, since they are extremely costly, and their insulation could easily be damaged by lightning, and they might even have their core more or less injured. Ordinary telegraph instruments are furnished with a simple protector, consisting of a fine wire W (Fig. 1), which fuses with too large a current, and a pair of plates P, one connected to earth E, the other to line L and separated by a fine air-gap as shown. This is quite enough to prevent the signalling current from leaking away, but a lightning discharge flashes across from one plate to another and does but little damage to the instrument. One of the cable protectors most used (which protects at least from dangerous currents) is the Saunders protector. It consists of a fine wire, through which the signalling current passes,

surrounded by a tube, connected to earth, which is provided with points projecting to the thin wire; this latter is kept taut by a spring. The idea is that the sparks will pass from the line outside by the points to earth, while the wire will fuse if too large a current passes. Directly the wire is broken the cable is automatically earthed, and thus protected.

Dr. Lodge has recently introduced new protectors, which apparently protect the insulation as well as the core; but they have been but little tried in practice.

In the case of electric light wires we have a new difficulty to contend with. A spark renders the air for an instant a conductor, and if between the wires there exists a large electrical pressure (such as is the case in arc-light circuits), a permanent flash will follow, and so large a current may flow as to damage

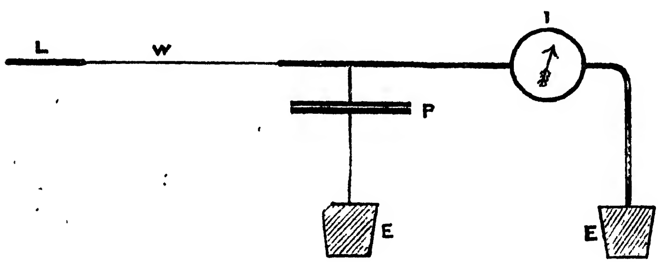
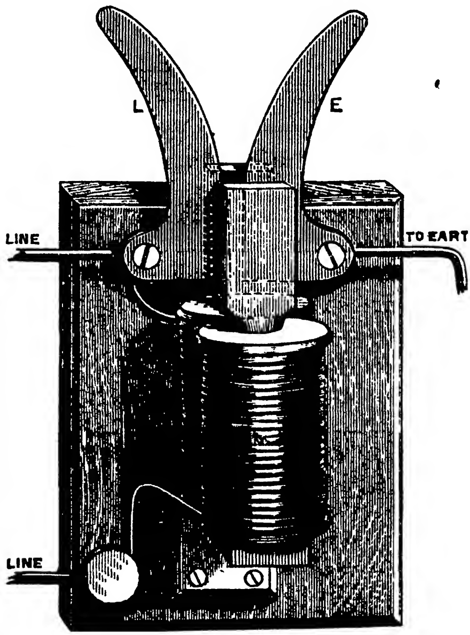


FIG. 1.

the dynamo, &c. Several devices have been proposed to avoid this danger; one of the most ingenious is that used by the Thomson-Houston Company (*see* Fig. 2). This protector consists of two cheeks L and E (Fig 2), one of which goes to the line L, the other to an earth-plate. These are placed between the poles of an electro-magnet M, which is kept energised by the current from the dynamo. Should lightning strike the line, it will spark from L to E and go to earth, and the dynamo current (being high pressure) would tend to follow it, and cause damage; this is prevented by the electro-magnet repelling the arc up to the higher part of the cheeks, when it goes out, owing to the distance being too large for the dynamo current to pass. The breaking of the arc (or its non-formation) can be procured in other ways, but the above is the simplest for a high-pressure circuit.

In conclusion it must be pointed out, that although a certain measure of protection to buildings, telegraph lines, dynamo plant, &c., can be obtained by the methods described, it is quite



impossible to protect absolutely against all risk from lightning. We can immensely minimize lightning risks by these means, but too little is known about the behaviour of currents and pressures so enormous for us to annihilate all risk.

The report of the Lightning Rod Conference (1881) contains a résumé of the general existing knowledge and practice.

The Electrician" Primers.—**No. 20.**

THERMOPILES.

If two dissimilar metals are brought into contact, and the point of contact is heated, a difference of electrical potential is set up.

Fig. 1 shows a closed electric circuit consisting of two dissimilar conductors A and B, making contact at M and N. If both the junctions are at any given temperature, the potential difference at M will be opposed to the equal potential difference

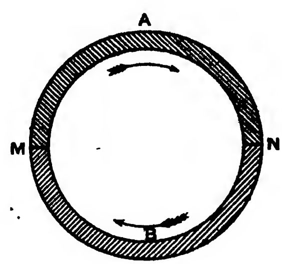


Fig. 1.

at N; and no current will be set up in the circuit. If, however, one junction is heated, the other being kept cool, there will be an electromotive force in the circuit which will be effective in producing a current; and the greater the difference of temperature, the stronger is the current produced. Such a pair of dissimilar metals, with hot and cold junctions, constitutes a *thermo-electric couple.* The most active pair of metals is antimony and bismuth; but, owing to the costliness of these, the less effective but cheaper metals, iron and copper, are frequently used. In Fig. 1, if A is of antimony or iron, and B of bismuth, or

copper, while M and N are respectively the hot and cold junctions, a current will be set up in the direction of the arrows.

The electromotive force due to a single *couple* is very small; but it will be seen that an increased E.M.F. can be obtained by arranging a number of pieces of metal in series, the junctions of dissimilar pieces being alternately hot and cold; the arrangement being similar to joining cells in series in a battery. In Fig. 2 a combination of this kind is shown; and when the pieces of metal are grouped compactly together in such a way that heat can be applied to one set of junctions, while the alternating set remains cool, the combination is called a *thermopile*.

Fig. 3 shows a small thermopile mounted on a stand and connected by conducting wires to a sensitive galvanometer. If the slightest temperature difference exists between the ends

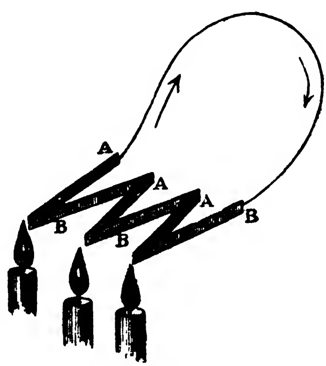


Fig. 2.

of this thermopile, a current is sent through the galvanometer, and the needle is deflected. The thermopile, therefore, acts as a most delicate thermometer, and as such it is of very great use in physical research. This, in fact, constitutes its chief utility.

The action of the thermopile being to convert heat directly into electric energy without the agency of moving machinery, much hope has been placed in it as a contrivance for developing electrical energy on a commercial basis. It is popularly supposed, and has from time to time been gravely suggested, that by means of large thermopiles electric lighting currents for whole streets or towns could be obtained directly from the inexpensive heat of a coal furnace; or that a double stroke of economy

could be effected by combining electric lighting thermopiles with warming stoves in the rooms of each private house. The fact remains, however, that the best behaviour of modern thermopiles gives no ground for these visionary hopes, but shows rather a high probability that thermo-electric generators will *not* be established on an economical and commercial basis.

The causes of inefficiency in these generators are mainly as follows:—The electromotive force due to a single pair of metals being so extremely small, a very large number of separate pieces are required, making the generator heavy, bulky, and expensive, and increasing the risk of breakdown at the junctions. If copper and iron are used, it would require more than 70,000 pieces of

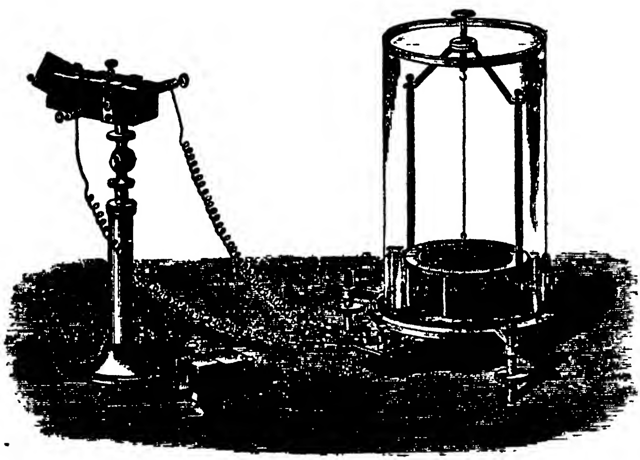


Fig. 3.

metal with alternate junctions, at a difference of temperature of 100°C., in order to develop 100 volts. It is also very difficult to maintain a large temperature difference, as the conductivity of the metals causes heat to pass through them from the hotter to the colder junctions, thus tending to equalise the temperatures. Moreover, the electric current developed in the generator has a similar tendency, the current warming the cold junctions and tending to cool the hot ones. To limit this tendency of heat to pass along the metals, the separate pieces require to be of considerable length, and this, together with the numerous junctions, involves a high internal electric resistance, so that a large proportion of power is wasted inside the generator. One supposed advantage of the

thermopile over moving machinery is the absence of wear and tear; but although in the former there are no moving parts, there is considerable depreciation. Thermopiles which are in constant use, and exposed to the action of high temperatures, are found to deteriorate, a molecular change taking place in the metals which results in a gradual reduction of power.

The most powerful thermopiles which have been constructed, up to the present time, have not exceeded an electrical power of 12 watts each, a power sufficient only for a glow lamp of about 3 candle-power. These are massive, bulky contrivances, heated by coal gas. Some recent tests made on thermopiles heated in this way, and on dynamos driven by gas-engines, show that the former require three times as much coal gas as the latter per unit of electrical energy produced. Gas engines of as much as 100 horse-power are commonly in use, and these, in conjunction with good dynamos, will develop electrical power sufficient for nearly 1,000 glow lamps of 16 candle-power each. Machinery of this power can be conveniently run in a very moderately sized engine-room, the space occupied, and the weight of machinery per unit of power, being extremely small as compared with the space and weight of thermopiles. Thus, in economy of space, as well as of working cost, thermo-electric generators are very inferior to dynamos driven by a gas-engine, or *a fortiori* by a steam-engine.

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